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THESIS

DEFINING STABILITY, SECURITY, TRANSITION, AND RECONSTRUCTION (SSTR) OPERATIONS REQUIREMENTS FOR FUTURE DEPARTMENT OF THE NAVY TRAINING AND ANALYTICAL MODELS AND SIMULATIONS

by

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The Department of Defense elevated stability operations to equal importance as combat operations. With 75 percent of the world's population located in the littorals, the Navy-Marine Corps team is poised to be the country's instrument of choice for military support to Stability Operations. This brings the need to train and plan for these non-traditional missions. Furthermore, simulations are force multipliers in both the training and planning arenas, but no current simulation exists that adequately addresses stability operations. This thesis reviews how Navy-Marine Corps leaders plan and train for restoring a civilian population's essential services, via the guidance of The Department of Defense Directive 3000.05 and National Security Presidential Directive 44. The objective for this thesis is to create a documented methodology, define requirements, and provide metrics that will assist analysts and instructors during naval support to Stability, Security, Transition, and Reconstruction (SSTR) operations. In addition, it evaluates the capability gaps in current simulations. Lastly, a conceptual model is proposed using water as a proof of concept essential service, and a prototype framework simulation is presented. This work provides a working foundation to begin developing the next generation of simulations that will support or warfighters into the next era of warfare.

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DEFINING STABILITY, SECURITY, TRANSITION, AND RECONSTRUCTION (SSTR) OPERATIONS REQUIREMENTS FOR FUTURE DEPARTMENT OF THE NAVY TRAINING AND ANALYTICAL MODELS AND SIMULATIONS

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ABSTRACT

The Department of Defense elevated stability operations to equal importance as combat operations. With 75 percent of the world's population located in the littorals, the Navy-Marine Corps team is poised to be the country's instrument of choice for military support to Stability Operations. This brings the need to train and plan for these non-traditional missions. Furthermore, simulations are force multipliers in both the training and planning arenas, but no current simulation exists that adequately addresses stability operations. This thesis reviews how Navy-Marine Corps leaders plan and train for restoring a civilian population's essential services, via the guidance of The Department of Defense Directive 3000.05 and National Security Presidential Directive 44. The objective for this thesis is to create a documented methodology, define requirements, and provide metrics that will assist analysts and instructors during naval support to Stability, Security, Transition, and Reconstruction (SSTR) operations. In addition, it evaluates the capability gaps in current simulations. Lastly, a conceptual model is proposed using water as a proof of concept essential service, and a prototype framework simulation is presented. This work provides a working foundation to begin developing the next generation of simulations that will support or warfighters into the next era of warfare.

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LIST OF ACRONYMS AND ABBREVIATIONS

ABM	Agent Based Models
AHC	Averting a Humanitarian Crises
BBN	Bayesian Belief Network
CAOCL	Center for Advanced Operational Culture Learning
CASTFOREM	Combined Arms and Task Force Evaluation Model
CERDEC	Communications-Electronics Research Development and Engineering Center
CIA	Central Intelligence Agency
CNO	Chief of Naval Operations
COIN	Counterinsurgency
COMBAT XXI	Combined Analysis Tool For the 21st Century
CORDS	Civil Operations Rural Development Support
COTS	Commercial, off-the-shelf
DES	Discrete Event Simulation
DIA	Defense Intelligence Agency
DIS	Distributed Interactive Simulation
DIME	Diplomatic, Informational, Military, and Economic
DoN	Department of the Navy
DoD	Department of Defense
DoS	Department of State
EBO	Effects Base Operation
EOD	Explosive Ordnance Disposal
FBCB2	Force XXI Battle Command, Brigade-and-Below
FM	Army Field Manual
EEA	Essential Elements of Analysis
EPG	Electronic Proving Ground
ESS	Essential Service System
HLA	High Level Architecture
H.R. 1084	Reconstruction and Stabilization Civilian Management Act of 2008
ISSAC	Irreducible Semi-Automated Adaptive Combat
IW	Irregular Warfare
JCATS	Joint Conflict and Tactical Simulation
JP	Joint Publication
LNO	Liaison Officer
M&S	Modeling and Simulation
MAGTF	Marine Air Ground Task Force
MANA	The Map-Aware Non-uniform Automata
MAS	Multi-Agent Systems
MCAG	Maritime Civil Affairs Group
MCCDC	Marine Corps Combat Development Command
MEF	Marine Expeditionary Force

MMEs	Major Mission Elements
MOE	Measure of Effectiveness
MOP	Measure of Performance
MORS	Military Operations Research Society
MPICE	Measuring Progress In Conflict Environment
MSDL	Military Scenario Definition Language
MTWS	Tactical Warfare Simulation
NATO	North Atlantic Treaty Organization
NECC	Naval Expeditionary Combat Command
NGO	Non Government Organization
NRL	Naval Research Laboratory
NSPD-44	National Security Presidential Directive 44
NSS	Naval Simulation System
NWDC	Naval Warfare Development Center
ONI	Office of Naval Intelligence
OR	Operation Research
OSAF	One Semi-Automated Forces
OSS	Objective OSAF
OSD	Office of the Secretary of Defense
OT&E	Operational Test and Evaluation
RUCG	Representing Urban Cultural Geography
PEO –STRI	Program Executive Office-Simulation Training and Instrumentation
PMESII	Political, Military, Economic, Social, Information, Infrastructure.
PSOM2	Peace Support Operations Model, Version 2
QDR	Quadrennial Defense Review
SEAS	Synthetic Environments for Analysis and Simulation
SISO	Simulation Interoperability Standards Organization's
SME	Subject Matter Expert
SPAWAR	Space and Naval Warfare System Command
SSTR	Military Support to Stability, Security, Transition and Reconstruction Operations
SSTRO JOC	SSTR Operations Joint Operational Concept
STORM	Simulation Testing Operations Rehearsal Model
TRAC	TRADOC Analysis Center
TRAC-WSMR	TRAC – White Sands Missile Range
TRADOC	U.S. Army Training and Doctrine Command
TOC	Tactical Operations Centers
USAID	U.S. Agency for International Development
USAOTC	U.S. Army Operational Test Command
USIA	United States Information Agency
USG	U.S. Government

EXECUTIVE SUMMARY

The tragedy of September 11, 2001 has reminded the U.S. that its vital interests are intertwined with the security and prosperity of other nation states—no matter how remote. Therefore, Department of Defense (DoD) Directive 3000.05 and National Security Presidential Directive 44 (NSPD-44), are focusing military operational concepts toward nation building and stability operations on equal footing with combat operations. This goal is to alleviate instability. Moreover, as population growth continues in coastal geographical areas around the world, there will be an increasing dependence on the naval component of the U.S. military to act. The challenge for the DoN is to maintain its proficiency in traditional naval missions, while enhancing its capability to affect regional and global stability. With today's globalization, the U.S. has the potential to feel negative consequences from instability around the world caused by mitigating factors, such as natural disasters, civil unrest, and war.

Before the U.S. embarks on Stability Operations, it is critical to apply training and analytical military simulations to provide guidance for strategic and operational decision makers. Trial and error solutions in the form of military operations are too costly in lives and financial resources. Training and analytical military simulations need to act as force multipliers that provide a better solution. Current military simulations, such as stochastic and deterministic models used in kinetic warfare combat analysis, are not a viable solution. These models range in complexity from solvable differential equations to complex adaptive systems, but they generally fail to address adequately Stability Operations. One of the core missions that the DoN is repeatedly called upon to support is restoration, provision, and maintenance of essential services during all phases of combat. The lack of a proper tool makes it hard for the Navy-Marine Corps team to plan for campaigns, provide analysis, or train personnel to assist stability operations.

The research questions addressed in this research include:

- What is the Navy's and Marine Corps' role in support of Stability, Security, Transition, and Reconstruction (SSTR) Operations? What are the unique challenges in planning, analysis, decision support and rehearsal to support that mission?
- Can metrics be developed to measure success of the naval operation supporting SSTR?
- Can agent based modeling address gaps in current analytical models used to model naval operation supporting SSTR Operations?
- What are the current analytical and training models of naval support to SSTR Operations and what are the capability gaps with respect to what is needed to provide a complete strategic picture to operations planners?
- Can non-kinetic models be derived and simulated to support staff training for naval operation supporting SSTR?

This thesis provides a background on stability operations, establish requirements for modeling restoration of essential services, and submit a simulation framework with the capability to simulate production, storage, transportation, and distribution of clean water to a populace. This conceptual model and implementation serve as a proof of concept. Prior to this thesis, there have been no established requirements for simulations for operations to restore essential services.

DoD Directive 3000.05 defines Stability Operations as "military and civilian activities conducted across the spectrum from peace to conflict to establish or maintain order in States and regions." Further, it delineates military support to SSTR as "[DoD] activities that support [U.S. Government] plans for stabilization, security, reconstruction and transition operations, which lead to sustainable peace." SSTR operations by the U.S. military can be traced to the country's first century of existence. From the late 18th century, the U.S. Army conducted law enforcement and patrolled the frontier to early 20th century, the U.S. Marine Corps responsibility of policing and stabilizing the Caribbean region. Since the end of the Cold War in 1991, the U.S. military has averaged an SSTR operation every two years, from humanitarian assistance to nation building in such diverse locations as Haiti, Somalia, Kosovo, Bosnia, Indonesia, Afghanistan, and Iraq.

The nature of SSTR operations and Naval capabilities in support of these operations need to be understood as background for identifying modeling and simulation requirements supporting analysis and training. For supporting restoration of essential services – specifically, water – the Navy Marine Corps team is capable of producing, storing, transporting, and distributing water. Furthermore, because of their organic command and control, DoN's platforms can provide a less overt assistance, while preserving the host nation's legitimacy.

As long as the model is supported by credible data, M&S can assist the analyst and trainer support the decision maker in preparing, planning, and executing the mission. For the analyst, simulations can minimize problems by creating a virtual laboratory in which civilian and military decision makers can experiment with variables in an operational environment. An instructor can use a simulation as a tool to accomplish training objectives that enlighten military professionals, while exposing them to a new environment and without worry of a wrong decision's catastrophic repercussion.

The Operational Environment in which the DoN functions in has become severely complex. Some would define this as a wicked problem because the dilemma that this country faces in the realm of global stability has incomplete, contradictory, and changing requirements. Furthermore, the solutions to those problems are too challenging to identify as such because of complex interdependencies. Unless requirements are captured prior to creating a conceptual model, then any solution will be flawed.

Modeling and architecture requirements provide a basis for subsequent conceptual modeling, design, and implementation of the model. This thesis identifies five – necessary but not sufficient – requirements for operations to restore restoration of essential service: averting humanitarian crises; critical inputs to social relationship models; maintaining the security of essential services; meeting the international standard for disaster relief; and collaborating with civilian organizations. Simulations must provide representations of these operations.

To be an effective tool for analysis and training, the model of restoration of essential services needs to be able to generate meaningful measures that can be used for evaluating progress in the conduct of those missions. Three criteria that constitute well-defined measures are commander's intent, mathematical properties, and utility. The first criterion encompasses the commander's intent of the simulation in which metrics are evaluated on relevancy—both to the indigenous population and to the mission. The second criterion is mathematical properties of good MOEs, which needs to be complete in its coverage and mutually exclusive. Furthermore, the output metrics should be sensitive to input data, so that the analyst does not inadvertently add inconsequential and all metrics should be measurable—either quantitative or qualitative. The third criterion concerns itself with how much utility the metric will have for a military decision maker based on comprehensible and non-ambiguous explanations.

The Navy Research Lab (NRL) and Naval Operations Assessment Division (N81) at a DIME-PMESII Modeling Requirements Workshop posed one critical issue: "What are the impact of disruption and/or enhancement of [water system] infrastructure on population's [water needs]?" This thesis provides a process to address this question. U.S. Army doctrine and Non Government Organizations (NGOs) publications divide this question into sub-objectives. The Army categorizes the restoration of an essential service into five elements: emergency medical care and rescue, food and water, emergency shelter, basic sanitation for sewage and garbage disposal, and prevent epidemic disease. However, it stops at simply providing an element like food and water and fails to cover the difficulties associated with distribution, disruption of these efforts and the subsequent reaction of the population. A humanitarian relief doctrine with the participation from 80 countries and 400 NGOs provides the needed amplification. This collaboration effort is called the Sphere Project, and it provides three water supply standards: 1) quantity, 2) quality and 3) water use.

Measurement of Performances (MOPs) for simulating Water standard 1 (these are items that the military decision maker can control) are:

- Production Amount -- Amount of water produced by a specific production facility every production cycle
- Production Service Time -- Amount of time a production facility takes to produce water in one production cycle
- Storage Capacity -- Amount of water that can be stored after being produced and before beginning to be transported to the distribution facility
- Transportation Amount -- Amount of water transported by a specific transportation method during each mission
- Transportation Service Time -- Amount of time a each mission takes to transport water from the storage unit to the distribution facility
- Distribution Amount -- Amount of water distributed by a specific distribution facility every distribution cycle
- Distribution Service Time -- Amount of time a distribution facility takes to distribute water in one distribution cycle
- Location of the non-indigenous owned distribution process -- geographical location of temporary distribution facilities. These can be NGO, U.S. military, or other relief organization operated distribution sites. This MOP is useful when measured against population locations.
- Location of a newly constructed element of the water infrastructure -- geographical location of a permanent addition to the water supply system. Typically this facility will have an owner and will be part of an overall produce-Store-Transport-Distribute process.
- Time to complete building a new element of the water infrastructure -- measure the time from beginning the construction until the facility is operational and provides any non-zero improvement to the water system.

Measurement of Effectiveness (MOEs) for Simulating Water Standard 1 are:

- Number of times a person does not receive a specified amount of water per time cycle (15 litres/day)
- Number of people that went without water because of the distance requirement
- Average Queuing Time for each Distribution Process (can be expanded to analyze the distribution of the queuing time)
- Average Service Time for each Distribution Process given a specified distribution amount requirement (20 litre per cycle) (can be expanded to analyze the distribution of the service time--but this is probably a parameter)
- Other MOEs can be derived from mathematical combinations of the MOPs and MOEs such as % of total population that is provided water

Model, architecture, and measurements requirements must be defined. Numerous methodologies can be applied to design the model to meet the requirements, but one approach of particular interest is agent-based modeling. Agent Based Models (ABMs) are computational models that simulate the actions and interactions of small solvable problem sets that lead toward emergent behavior. An agent in ABM is merely one part of the overall system. To maximize the utility of the agent, the rest of the system needs to be defined. The Ferber Multi-Agent Systems (MAS) design encompasses five key elements: Environment, Agent, Operations, Objects, and Laws. In MAS, intelligent agents are interacting with each other leading toward emergent behavior.

The self-adaptive nature of some of these models may facilitate broad exploration of battlefield scenarios and permit the possibility of gaining substantial insights into both military and non-military emergent behaviors. This may be especially pertinent for a non-linear battlefield with distributed tactical units. However, before proceeding with new model design and implementation, the state of the art needs to be evaluated to determine if existing models can meet the stated requirements.

The next step is to evaluate the simulations that are in use or actively being developed against the established requirements previously discussed. Over the past several decades, military simulations have largely focused on kinetic warfare. Therefore, simulations that have been not been in active development since the creation of SSTR doctrine are assumed unable to support restoration of essential service requirements. The remaining simulations must support all requirements and produce anticipated MOEs. A representative sample has been selected based on their established reputation within DoD or by virtue of their current funding levels:

1. Analysis

- Combined Arms Analysis Tool for the 21st Century (COMBAT XXI)
- Pythagoras
- Naval Simulation System (NSS)
- Simulation Testing Operations Rehearsal Model (STORM)

2. Training

- Marine Air Ground Task Force (MAGTF) Tactical Warfare Simulation (MTWS)
- Joint Conflict and Tactical Simulation (JCATS)
- One Semi-Automated Forces (OneSAF)

3. Commercial and International

- Map-Aware Non-uniform Automata (MANA)

- Synthetic Environments for Analysis and Simulation (SEAS)
- Performance Moderator Function Server (PMFserv)
- Peace Support Operations Model, Version 2 (PSOM2)

The overall assessment of capabilities of these simulations to support restoration of essential service requirements is that existing simulations cannot meet all the requirements. In their respective domains, these simulations perform very well for their intended purposes. Moreover, each simulation has been designed to fulfill a specific niche role, but none has adequately branched into simulating military and non-military aspects of operations to restore essential services. Even though there are many possibilities of simulations, at the time of this writing, the simulations chosen are ones that key military analysis or training organizations are actively developing or evaluating. Since no existing simulation can satisfy the requirements, a new conceptual model must be designed.

The conceptual model translates requirements and metrics into a simulation design. Furthermore, the conceptual model describes the components and is the guiding document during the implementation. This conceptual model must satisfy the stated requirements and be able to provide the metrics that were aforementioned. Using the requirements for restoration of essential services, a discrete-event simulation (DES) MAS design can be created. A DES provides defined state variables, state transitions corresponding to events, and the scheduling of additional events. Furthermore, the DoN's capabilities for providing essential services are easily represented in a DES component, and effects on the population are calculable in a MAS. The DES MAS proposed in this thesis is able to satisfy the defined requirements. After the conceptual model is confirmed to represent the environment correctly, a specific software implementation can begin.

The implementation of the conceptual design is the final step in the process. A prototype framework simulation can be written from event graphs that describe conceptual model. Extending the event graph foundation, a SimKit software implementation can be designed around the Ferber MAS design. Each of the elements in a MAS will be precisely defined with loosely coupled event graphs that will satisfy the conceptual model. At the completion of the event graph design, a sample input parameters and out is provided as a proof of concept.

This implementation serves as a proof of concept implementation of the conceptual model and demonstrates key concepts of DES MAS design. By maintaining the loosely coupled philosophy throughout the design and implementation procedures, each component can be exchanged for another representation of the component process. Furthermore, these extensions to standard event graph design allow simulation designers to consider many different levels of aggregation while maintaining loose coupling. From this simulation implementation, many areas for future work are now present and several conclusions can be drawn.

With the right procedures and practices, simulations are a force multiplier that help DoN prepare for new missions. Overall, this thesis adds to the M&S of military support to SSTR Operations body of knowledge. First, a process was followed that allows a solid foundation to flourish into a proof of principle simulation. Second, during the research effort, references and documents that each describes a small piece of the SSTR problem were assembled. Third, in the absence of DoN requirements, several requirements were presented as a starting point. Lastly, based on the above requirements, a loosely coupled DES MAS conceptual model was designed and implemented.

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I. INTRODUCTION

> *To fail to meet those obligations now would be disastrous; and, in the long run, more expensive. For widespread poverty and chaos lead to a collapse of existing political and social structures which would inevitably invite the advance of totalitarianism into every weak and unstable area. Thus, our own security would be endangered and our prosperity imperiled. A program of assistance to the underdeveloped nations must continue because the Nation's interest and the cause of political freedom require it.*
>
> -- John F. Kennedy[1]

A. PROBLEM STATEMENT

The tragedy of September 11, 2001 has reminded the U.S. that its vital interests are intertwined with the security and prosperity of even the most obscure nation states.[2] It is in America's best interest to mitigate factors ─ such as natural disasters, civil unrest, and war ─ that lead any nation toward instability. Historically the U.S. government has utilized the military to resolve these causes due to its manpower and established infrastructure. The Department of the Navy (DoN) plays a particularly important role because more than 75 percent of the world's population, 80 percent of the capital cities, and 90 percent of the world's trade is adjacent to or transiting an ocean, sea, bay, or river.[3] Increasing resource shortages added to population growth in these areas can lead to the destabilization of many nation states, such as Somalia in May 2008. In this scenario, there will be an increasing dependence on the naval

[1] USAID's History Website; the quote taken from the section explaining the reason why the United States should continue a foreign economic assistance program. Available at http://www.usaid.gov/about_usaid/usaidhist.html. Accessed on 3 July 2008.

[2] *A Cooperative Strategy for 21st Century Seapower*, 2.

[3] *Naval Operations Concept 2006*, 9.

component of the U.S. military. The challenge for the DoN is to maintain its proficiency in traditional naval missions, while enhancing its capability to affect regional and global stability.

As with many operations, before the U.S. embarks on Stability Operations, it is critical to apply training and analytical military simulations to provide guidance for strategic and operational decision makers. Trial and error solutions in the form of military operations are too costly in lives and financial resources. Training and analytical military simulations need to act as a force multiplier that provides a better solution. Moreover, current military simulations, such as stochastic and deterministic models used in kinetic warfare combat analysis, are not a viable solution. These range from solvable differential equations to complex adaptive systems, but they generally fail to address Stability Operations, specifically regarding restoration, provision, and maintenance of essential services during all phases of combat. The lack of a proper tool makes it hard for the Navy or the Marine Corps to plan for campaigns, provide analysis, or train personnel to assist stability operations. This thesis will provide a background on stability operations, establish requirements for modeling reconstruction operations, and submit a simulation framework for modeling restoration of essential services – the capability to make and distribute clean water to its populace – as a proof of concept, in order to assist in solving this problem. Prior to this thesis, there have been no established requirements for simulations for operations to restore essential services.

B. CURRENT EXAMPLES OF INSTABILITY IN THE WORLD

To prevent and counter instability in the world a decision maker needs to know the root causes and how stability operations can affect a state. The term "instability" is in reference to a state that is incapable of maintaining order or providing essential services to its populace. The task of performing stability operations in light of competing political, social, and economic factors is overwhelming. Horst Rittel identifies such problems as a "*wicked problem,"*[4] one in which a specific root cause is unidentifiable. Furthermore, in attempting to solve a wicked problem, the solution of one portion of the conundrum may reveal other complex problems not originally considered.[5] Although the root cause of instability may never be discovered, three key sources of instability are natural disasters, civil unrest and war.

1. Natural Disasters

Throughout the 1990s, Burma[6] was a country in turmoil because its military refused to recognize election results and imprisoned the opposition leader. Then, on 2 May 2008, Cyclone Nargis made landfall in Burma, killing 150,000 people[7] and creating a state of emergency in five regions of the country.[8] The political turmoil in conjunction with flooding impaired the Burmese people's ability to obtain clean water, proper sanitation and food. Together these factors increased the population of disease carrying insects and contributed to

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[4] Jeff Conklin (2006), *Dialogue Mapping: Building Shared Understanding of Wicked Problems*, West Sussex, England: John Wiley & Sons, Ltd., 12-17. In this book, Dr. Horst Rittel is quoted as defining wicked problems as having incomplete, contradictory, and changing requirements with solutions to those problems too challenging to identify as such because of complex interdependencies.

[5] *Dialogue Mapping: Building Shared Understanding of Wicked Problems*, p. 12-17.

[6] Burma is also known as Myanmar; however, the U.S. State Department currently does not recognize the country name "Myanmar." The Department of State's country website for Burma is available at http://www.state.gov/p/eap/ci/bm/. Accessed 5 July 2008.

[7] *Country Alert: Burma*, The Fund for Peace, May 2008 update. The website reports that the casualty in Burma range from an estimate of 100,000 to 150,000 dead or missing. Available at http://www.fundforpeace.org/web/index.php?option=com_content&task=view&id=258&Itemid=404. Accessed 5 July 2008.

[8] Kocha Olarn, Raja Razek and Dan Rivers(4 May 2008), "Red Cross aid rushed to Myanmar victims," *CNN.com.* Retrieved 5 July 2008 from http://www.cnn.com/2008/WORLD/asiapcf/05/04/myanmar.cyclone/index.html?iref=newssearch. The article stated that there was a state of emergency declared in five regions: the city of Yangon, Irrawaddy, Pegu and the states of Karen and Mon.

rising concern for large-scale outbreaks of malaria and dengue fever.[9] The cyclone has exposed Burma's rampant political corruption and leaves the country vulnerable to transnational crime.[10]

Similar to Burma, Pakistan's political chaos may leave it vulnerable to further destabilization from a natural disaster. The assassination of former Prime Minister Benazir Bhutto dramatically highlights the danger. Despite this tumultuous political backdrop, the U.S.-NATO forces proved the value of stability operations in the aftermath of the 8 Oct 2005 earthquake that killed 80,000 people and isolated three million from basic necessities such as food, clean water, and access to hospitals. After the Pakistan government requested international aid, NATO sent in 3400 tons of goods, repaired 60 km of roads, and medically treated 8500 people.[11] The success of this mission has contributed to maintaining Pakistan as a critical ally in southwest Asia.

2. Civil Unrest

Regarding civil unrest, since the 1991 coup d'état of Dictator President Mohammad Barre, Somalia has been in a state of near anarchy. This situation was the result of continuous fighting between the tribes of that country. A transitional government has been unable to take power in the capital, Mogadishu, and the country has no state institutions to provide essential services.[12] As recently as May 2008, huge riots took place in Mogadishu because of the deteriorating humanitarian situation caused by inflated food prices and a

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[9] Barbara Starr (6 May 2008), "Some aid delivered in cyclone-ravaged Myanmar," *CNN.com*. Accessed 5 July 2008 from http://www.cnn.com/2008/WORLD/asiapcf/05/06/myanmar.relief/index.html?iref=newssearch.

[10] CRS Report for Congress, (16 April 2008), *Burma and Transnational Crime* (Order Code RL34225), Washington, DC: Congressional Research Service, p. 1.

[11] Jamie Shea (Director of Policy Planning), (8 March 2006), *Lessons learned in Pakistan: NATO providing Humanitarian aid, and the role of the NATO Response Force* [Online Video Forum]. Brussels: NATO. Transcript available online: http://www.nato.int/docu/speech/2006/s060306a.htm. Accessed 5 July 2008.

[12] Somalia Country Page, The Fund for Peace, available at http://www.fundforpeace.org/web/index.php?option=com_content&task=view&id=298&Itemid=453. Accessed 5 July 2008.

sustained drought. More than a third of the country's population requires assistance.[13] As a result, the region is experiencing a severe refugee crisis due to the mass exodus from Mogadishu. Instability will increase without an established government or international intervention to stop the warring factions and provide critical essential services to the population.

3. War

Wars cause instability by affecting distribution of governmental services, trade, economic investment and many other facets of life.[14] Even with today's broad definition of a *limited war*, most wars affect a country's infrastructure and disrupt basic governmental services.[15] Wars in general do not follow the original plan nor are their effects contained within predefined borders on a map. Historically, wars have been felt far beyond the local or regional area and at present have moved on to a global scale. With today's globalization, the rest of the world always has the potential to feel the negative consequences of that war, politically, economically, and socially. In the case of Operation Iraqi Freedom, major combat operations ended a few weeks after the initial invasion; yet five years later, stability and security are ongoing. Immediately after the toppling of Saddam Hussein's government, insurgents began a campaign of targeting Iraqi and Allied civilians, the new Iraqi police force, and key infrastructure systems.[16] The stress these attacks put on the entire National system initially overwhelmed the capabilities of the Iraqi government. Since governmental services and essential services are still developing, the presence of continued armed conflict

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[13] Lutfi Sheriff Mohammed and Edmund Sanders (6 May 2008), "Somalis riot over food prices," *Los Angeles Times*. Retrieved 5 July 2008 from The Seattle Times' Associated Press website: http://seattletimes.nwsource.com/html/nationworld/2004394501_somalia06.html.

[14] Clausewitz, *On War*; p.75-76.

[15] "The degree to which a war will be limited is, in the end, determined by political and military considerations of relative strength" Michael Handel (2001), *Masters of War*, London: Frank Cass, p. 288. In other words, the objective of limited war is less than the unconditional defeat of the enemy.

[16] Iraq Country Page, The Fund for Peace, available at http://www.fundforpeace.org/web/index.php?option=com_content&task=view&id=295&Itemid=465. Accessed 5 July 2008.

during phase 4 of the Phasing Model (see Figure 1)[17] has perpetuated a state of instability. This has led to an estimated 2 million Iraqis taking refuge in neighboring countries like Syria and Jordan.[18]

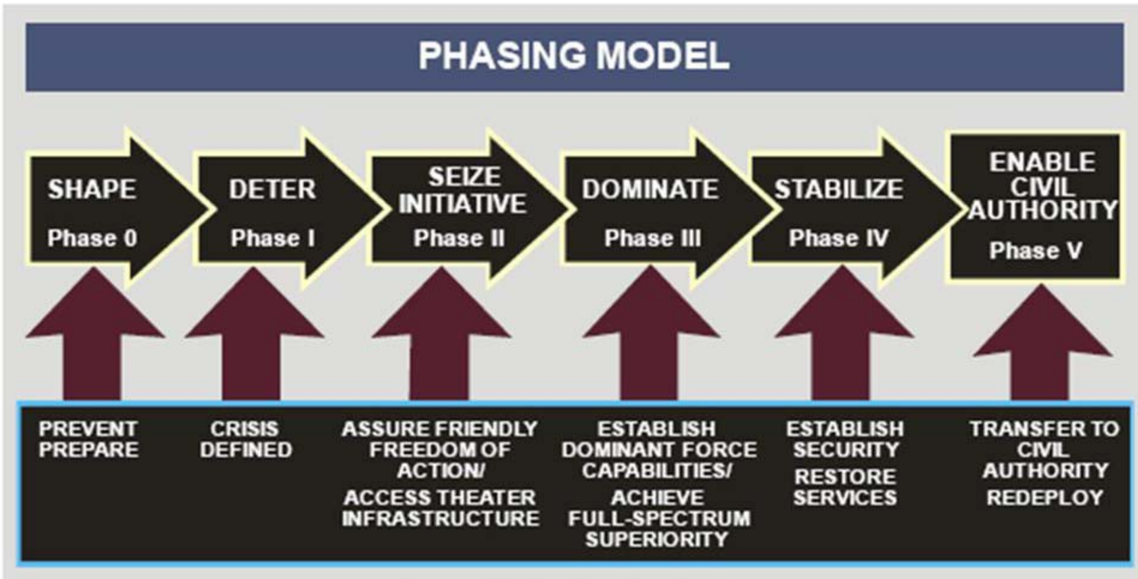

Figure 1. Phases of a Joint Campaign or Operation.

The focus of this thesis is on the Navy and Marine Corps role in the areas of "Restoration of Essential Services" in all Phases of the phasing model of the joint campaign or operation; in particular, to identify requirements for modeling and simulation support to training and analysis in this critical area of today's operations.

C. IMPORTANCE TO THE UNITED STATES

With the end of the Cold War, instability has created political vacuums that cause regional instability. Given the U.S.'s global alliances, trade, and unique military capability to project power, it is often placed in a position of being the

[17] *Joint Publications 3.0, Joint Operations*, (Change 1 update, 13 February 2008), p. IV-27. Phasing Model emphasizes that a campaign or an operation within theater conflicts generally consists of six sequential phases – shape, deter, seize the initiative, dominate, stabilize, and enable civil authority.

[18] Iraq Country Page, The Fund for Peace.

sole power and the only state capable of acting. As recent history has proven if instability is left unchecked, it often escalates to infringe on American policy interests.

Afghanistan is the best example of the U.S. failing to avert the dangers of instability. The 1989 withdrawal of the Soviet occupation force left Afghanistan in a state of civil war, which did not end until 1992. The U.S. was secretly training and funding the Mujahideen until funding ended with the Clinton administration's inauguration.[19] As the U.S. learned in Iraq, the conclusion of hostilities during phase 4 operations is a critical time to establish a stable nation. In the case of Afghanistan, "there were no roads, no schools, just a destroyed country – and the United States was washing its hands of any responsibility;" leaving Afghanistan without the rule of law and lacking the most basic services.[20] This was a perfect breeding ground for extremists like Osama bin Laden and the Taliban. Had these conditions been resolved, the US may have helped avoided the catastrophe of September 11. The U.S. tacitly gave Osama bin Laden the haven he needed to start a global conflict by ignoring reconstruction efforts and leaving the combination of U.S. weaponry and well-trained combat-experienced soldiers in Afghanistan waiting for someone to lead them.

Some argue that it is impractical for international intervention during a nation's establishment of interim governance, especially if phase 3 operations were conducted. In Dr. Karen Guttieri and Jessica Piombo's book, *Interim Governments – Institutional Bridges to Peace and Democracy*, Daniel Serwer stated, "any rational person should think twice before undertaking the effort."[21] No one doubts that stability operations are costly, absorb national resources, and

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[19] Steve Coll (2004), *Ghost Wars*, New York: Penguin Books, p. 4. See also, Lawrence Wright (2006), *The Looming Tower*, New York: Vintage Books, p. 259-262.

[20] George Crile (2003), *Charlie Wilson's War*, New York: Grove Press, p. 522.

[21] Karen Guttieri and Jessica Piombo (Eds.), (2007), *Interim Governments: Institutional Bridges to Peace and Democracy?*, Washington, D.C.: United States Institute of Peace, p.350. Daniel Serwer is the author of Chapter 15 in Guttieri and Piombo's book. Both Dr. Guttieri and Dr. Piombo are professors at the Naval Postgraduate School in the Cebrowski Institute and National Security Affairs Department, respectively.

requires much time. It is a wicked problem, and deserves intense detailed analysis by trained professionals. Nevertheless, one must consider the cost if the U.S. ignores instability around the world. Would it lead to another failed state such as Afghanistan that became a base of operations for Al Qaida? Therefore, Mr. Serwer's commentary contravenes stated U.S. policy and ignores the historical de facto of American success stories, such as the Greek Civil War and the Huk Rebellion in the Philippines.

For over forty years, the Foreign Assistance Act of 1961 has guided American policy with regard to stability operations. Congress declared that that it was in the United States' interest to assist developing countries so they could participate in a free, open, and equitable international economic system.[22] In section 108.52.a Congress stated:

> it is therefore the intention of Congress to…if necessary, defeat aggression, facilitating arrangements for individual and collective security, assisting friendly countries to maintain internal security, and creating an environment of security and stability in the developing friendly countries essential to their more rapid social, economic, and political progress.[23]

The Foreign Assistance Act of 1961 guides decision makers and validates the need for foreign intervention when instability threatens U.S. national security. It also emphasizes creation of a worldwide community of democracies and sets the foundation for *the National Security Strategy of the United States of America*, the National Security Presidential Directive 44 (NSPD-44), and Department of Defense (DoD) Directive 3000.05. Each member state must meet the needs of its citizens and the nation's government must act responsibly in the international system.[24] The National Security Strategy is founded upon two pillars. First, it promotes freedom, justice, and human dignity, in hopes of dissuading tyranny

[22] U.S. House of Representatives and U.S. Senate, Committee on International Relations and Committee on Foreign Relations (January 2006), Legislations on Foreign Relations through 2005 (24-796PS, Volume I-A), Washington, DC: U.S. Government Printing Office, p. 153.

[23] Ibid., p. 250.

[24] *The National Security Strategy of the United States of America* (16 March 2006), p. 1.

and promoting effective governance.[25] Second, it calls for the U.S. to confront autocratic governments from denying services to their citizens (Figure 2 illustrates the pillars of National Security Strategy).[26] The foundation of these pillars is a policy of global stability. By working to improve a struggling nation and halting transnational criminal and terrorist organizations from conducting activities inside its borders, the U.S. can transform breeding grounds for illicit behavior into powerful diplomatic, economic, and political allies. Promotion of democracy through stability operations is one of the best defenses of America.

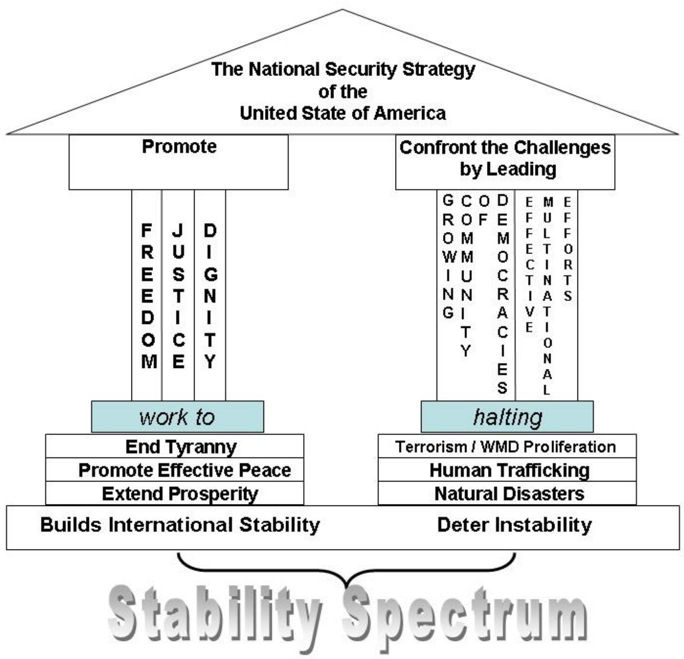

Figure 2. Pillars of the National Security Strategy.

NSPD-44 and DoD Directive 3000.05 were precursors to the National Security Strategy. Both documents explain how U.S. government agencies coordinate, plan, and implement reconstruction and stabilization assistance transition from conventional combat so as to avoid civil unrest that can escalate into an insurgency. NSPD-44 grants the Department of State (DoS) the authority

[25] *The National Security Strategy of the United States of America* (16 March 2006), p. ii.

[26] Ibid., p. ii.

to develop, improve, and implement the administration's foreign policy.[27] DoD Directive 3000.05 defines the military's responsibility in supporting Stability, Security, Transition and Reconstruction (SSTR) Operations. The two documents amplify the President's direction that DoS is the "supported unit" and DoD is the "supporting unit" for SSTR Operations.

Unfortunately the planning and training for international intervention by civilian agencies has been haphazard at best.[28] In the past, coordinated civil-military operations were ad hoc such as the introduction of the Civil Operations Rural Development Support (CORDS) in South Vietnam in 1967.[29] As the war in Vietnam highlights, thirteen years after the U.S. started providing aid, makeshift efforts in stability support from U.S. military and civilian agencies can have disastrous consequences. The U.S. needs to approach SSTR operations with a level of effort equal to traditional military operations. This will require organization, planning, and exercises. Modeling and simulation can provide analysts the ability to explore many problems before execution of SSTR and give instructors access to previously unavailable training environment.

D. SCOPE

The 2006 U.S. Joint Forces Command's *Military Support to Stabilzation, Security, Transition, and Reconstruction Operations Joint Operational Concept* (SSTRO JOC) describes reconstruction of essential services as a major mission element (MME) at the strategic level. [30] Army Field Manual 3-0 (FM 3-0) expands the definition at an operational level to include:[31]

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[27] National Security Presidential Directive/NSPD-44 (7 December 2005), p. 2-3.

[28] *Interim Governments: Institutional Bridges to Peace and Democracy?,* p. 350.

[29] Guenter Lewy (1978), *American in Vietnam*, Oxford: Oxford University Press, pp. 123-125. CORDS was an ad hoc civil/military organization that consisted of personnel from AID, DoS, CIA, USIA, and the White House, who served under soldiers (and vice versa) in Vietnam.

[30] Joint Forces Command . (2006). *Military Support to Stabilization, Security, Transition, and Reconstruction Operations Joint Operation Concept (SSTRO JOC)*. (Version 2.0). Washington, DC: U.S. Government Printing Office, p. 2-3

[31] Department of the Army. (2008). *Operations* (Field Manual 3-0). Washington, DC: U.S. Department of the Army, Chapter 3, p. 13.

- Emergency medical care and rescue
- Food and water
- Emergency shelter
- Basic sanitation for sewage and garbage disposal.
- Prevent epidemic disease

By itself, water scarcity can contribute to insecurity at the global level and endanger the national security of the United States.[32] The Poor Act of 2005 stated:

> It is the sense of Congress that United States programs to support and encourage efforts around the world to develop river basin, aquifer, and other watershed-wide mechanisms for governance and cooperation are critical components of long-term United States national security and should be expanded.

Therefore, the scope of the thesis is focused on modeling and simulation requirements in support of analysis and training of reconstruction operations to restore a region of interest's capability to make and distribute clean water to its populace.

E. APPROACH AND ORGANIZATION OF THE DOCUMENT

First, the nature and extent of SSTR Operations and the Department of the Navy's (DoN) capability and requirements for restoring essential services must be understood. This is presented in Chapter II. That chapter also discusses how modeling and simulation can assist analysts and trainers by representing the operational environment and providing a means of exploring that environment. The operational requirements lead to a set of modeling and simulation requirements identified in Chapter III and a set of necessary metrics (measures of performance and measures of effectiveness) identified in Chapter IV. The capability to compute the identified metrics will enable the military decision maker to define and quantify the relative performance of essential services restoration. Following description of the software, architecture, and measurement

[32] Legislations on Foreign Relations through 2005, p. 546-553.

requirements, the modeling and measurement methodology to address the requirements needs to be determined. Numerous modeling and simulation techniques are applicable, but the approach considered most promising is agent-based simulation and multi-agent systems. This modeling approach is discussed in Chapter V. The thesis then evaluates capabilities of current simulations to address the identified requirements and to provide the proper metrics. That evaluation is provided in Chapter VI. As will be seen, no current simulations are suitable for the requirements identified herein; a new simulation capability is needed. A conceptual model for that simulation is provided in Chapter VII, followed by a description of the implementation in Chapter VIII. The thesis concludes with Conclusions, Recommendations, and Future Work in Chapter IX.

II. REQUIREMENTS AND CAPABILITIES FOR MODELING RESTORATION OF ESSENTIAL SERVICES

For in this modern world, the instruments of warfare are not solely for waging war. Far more importantly, they are the means for controlling peace. Naval officers must therefore understand not only how to fight a war, but how to use the tremendous power which they operate to sustain a world of liberty and justice, without unleashing the powerful instruments of destruction and chaos that they have at their command.

-- Admiral Arleigh Burke[33]

A. INTRODUCTION

The nature of SSTR operations and Naval capabilities in support of these operations need to be understood as background for identifying modeling and simulation requirements supporting analysis and training. This chapter provides further background in these operations and the challenges facing the U.S. military. The chapter discusses modeling and simulation (M&S) and the ways that M&S can support the military analyst and training instructor, followed by discussion of the importance of credible data as the foundation for the model.

B. HISTORY OF SSTR

Both the U.S. and British navies have a history of SSTR Operations.[34] During the early 19th Century, the British executed seapower for the purposes of SSTR.[35] There was no grand design for the British to conduct global

[33] Admiral Arleigh Burke, CNO, 1 August 1961, Change of command address at Annapolis, MD [Arleigh Burke, Speeches, Box 1, Operational Archives Branch, Naval Historical Center] Available at http://www.history.navy.mil/trivia/trivia02.htm. Accessed on 11 July 2008.

[34] Dr. John Ferris, Professor, University of Calgary, provided an advance copy of a chapter at the Navy 2008 Stability & Security Conference from a yet unpublished book, *Naval Peacekeeping and Humanitarian Operations*, edited by James J. Wirtz; Jeffrey A. Larsen. The chapter is titled, "SSTR as History: The British Imperial Experience, 1815-1930", with an expected release date of 28 October 2008 and will be published by Taylor & Francis. (personal communication, 31 January 2008).

[35] Ibid., p. 1.

stabilization. Nonetheless, their effort in SSTR supported legitimacy, opposed despotism, and maintained order for greater access to trade.[36] By dominating the world's seas, the British controlled most of the naval trade routes.[37] In this period, known as the "Pax Britannica," Britain policed the oceans and created the first integrated political and economic system. Britain's de facto SSTR Operations influenced trade and world markets, spread the English language and European technology, forged the British Imperial system of measures, set the rules for commodity markets based on English common law, and pioneered parliamentary democracy.[38]

SSTR operations by the U.S. military can be traced to the country's first century of existence. In the late 18th century, the U.S. Army conducted law enforcement and patrolled the frontier, especially when dealing with "Indian affairs."[39] Communities grew within the vicinity of the forts, and soldiers used engineering skills learned at West Point to help in national development.[40] During the country's expansion across the continent, the military conducted stability operations while waging irregular warfare against the American Indians. In fact, U.S. soldiers played a critical role in developing the country's infrastructure, promoting local education and stimulating economic growth.[41] Other activities that can be categorized and traced to the U.S. military are Peace Operations, Homeland Security, Counterinsurgency, Security Assistance, Humanitarian and Civic Assistance, Support to Insurgencies, Support to

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36 SSTR as History, p. 5-6.

37 Ibid., p. 7, Per Dr. Ferris, in 1816, Britain tried to create an international naval league against the slave trade and the Barbary pirates. The intent was to defend all members of the league and not those that declined to join.

38 Andrew Porter (1998). The Nineteenth Century, *The Oxford History of the British Empire*. Oxford University Press, p. 323.

39 Ferris, *SSTR as History: The British Imperial Experience, 1815-1930*, p. 3-4.

40 Ibid., p. 3-4.

41 Ibid., p. 5.

Counterdrug Operations, Combating Terrorism, Noncombatant Evacuation Operations, Arms Control, and Show of Force.[42]

In the early 20th century, the U.S. Marine Corps became proficient in SSTR operations, especially nation building. Marines had the responsibility of policing and stabilizing the Caribbean region. They occupied Haiti from 1915 to 1935 and the Dominican Republic from 1916 to 1924. Moreover, during the mid 1920s, the Marines intervened and ended the Nicaraguan civil war.[43] As a result of these missions, the Marines gained enormous experience in the domain of SSTR. By 1940, the Marines took lessons learned from their military operations and published *The Small Wars Manual.* This manual codified training, planning, and initial combatant operations. It also provided methods for disarmament of the population, established procedures for effective military government, defined best practices for a transfer of power, and standardized methods for withdrawal of forces. Although the manual was and still is a critical doctrinal tool, it requires updating for modern SSTR operations and strategy.

During the post World War II era, U.S. forces continued SSTR operations. After combat operations were completed, the U.S. military assisted with reconstruction in occupied Japan and Germany. Operations during the Vietnam conflict began redefining civil and military roles to reflect current SSTR trends. Since the end of the Cold War in 1991, the U.S. military has averaged an SSTR operation every two years, from humanitarian assistance to nation building in such diverse locations as Haiti, Somalia, Kosovo, Bosnia, Indonesia, Afghanistan, and Iraq.[44] These operations are intricately intertwined in the U.S. military's history and can provide key lessons learned for follow on military generations.

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[42] Lawrence Yates (2006). *The U.S. Military's Experience in Stability Operations, 1789-2005*, Fort Leavenworth, Kansas: Combat Studies Institute Press, p. 2. Lawrence Yates wrote in his paper that many kinds of activities fell under the "rubric of stability operations."

[43] Ibid., p. 10.

[44] Larry Wentz and Michael Baranick (2004), S*tability and Reconstruction Operations: What we can learn from history*, (Publication Paper, National Defense University, 2004), p. 10.

C. IMPORTANCE OF WATER IN SSTR OPERATIONS

U.S. policy makers have determined that SSTR operations, especially humanitarian assistance and disaster relief, provide enormous benefit to U.S. interest. The 2006 *Quadrennial Defense Review* (QDR) *Report* states that "preventing crises from worsening and alleviating suffering are goals consistent with American values."[45] National Security Advisor Condoleezza Rice noted that the Asia tsunami of 2004 was an opportunity for the U.S. to extend its influence in Indonesia, a region noted for tacit support to religious extremist groups like al Qaeda.[46] The QDR further states that dealing with the problem in Phase 0 of the Phasing Model (discussed in Chapter 1) can prevent the aftermath of a natural disaster or war from developing into a wider crises.[47] Furthermore, SSTR is essential in Phase 4 operations:

> Quick action to relieve civilian suffering, train security forces to maintain civil order and restore critical civilian infrastructure denies the enemy opportunities to capitalize on the disorder immediately following military operations and sets more favorable conditions for longer term stabilization, transition and reconstruction.[48]

Properly conducted SSTR demonstrates American compassion and builds foreign goodwill toward the U.S., thereby protecting U.S. interests.

Throughout mankind's history, water has been the most essential item for stability and development, making it a key component of SSTR. Doctrine shows that the demand for food and water for growing populations will increase the chance for conflict. FM 3-0 states, "by 2015, 40 percent of the world's population will live in 'water-stressed' countries"[49] setting the stage for U.S. national

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[45] Department of Defense (2006), *Quadrennial Defense Review (QDR) Report*, Washington, DC: U.S. Government Printing Office, p. 12.

[46] Agence France Presse (January 18, 2005), Condi Rice: Tsunami Provided "Wonderful Opportunity" for U.S., *Commone Dreams.org News Center*, Accessed August 4, 2008, from http://www.commondreams.org/headlines05/0118-08.htm.

[47] *QDR Report*, p. 12.

[48] Ibid. p. 91.

[49] FM 3-0, p. 1-2.

interests to be threatened. Now is the time to address the problem and identify where SSTR Operations can provide solutions. For this critical mission, SSTR simulations will provide analysts a cost-effective, efficient and effective environment to civilian and military decision makers.

D. PROPERTIES OF SECURITY, STABILITY, TRANSITION, AND RECONSTRUCTION (SSTR)

Doctrine, specifically NSPD-44, officially tasks U.S. Government (USG) agencies to coordinate, plan, and implement reconstruction and stabilization assistance for foreign nations in transition from conflict or civil strife.[50] It also requires both DoS and DoD to integrate stability operations into military plans when "relevant and appropriate."[51] Legislation on Foreign Relations through 2005 authorized "support for a nation emerging from instability" and further directed U.S. agencies on the "creation and strengthening of systems to provide other services such as…water."[52] Current legislation, Reconstruction and Stabilization Civilian Management Act of 2008 (H.R. 1084), has been approved by the U.S. House of Representatives and is waiting debate by the U.S. Senate. It establishes the Office of the Coordinator for Reconstruction and Stabilization within the DoS to accomplish these missions.[53] H.R. 1084 authorizes the DoS to establish a Response Readiness Corps that will consist of government and private industry subject matter experts that would deploy to the region needing assistance. The Response Readiness Corps is expected to work in conjunction with Non Governmental Organizations (NGOs) and U.S. Foreign Military Services.

[50] NSPD-44, p. 1.

[51] Ibid., p. 2-5.

[52] Legislations on Foreign Relations through 2005, Sec. 1304 of Public Law 99–399.

[53] U.S. House of Representatives (March 2008), Reconstruction and Stabilization Civilian Management Act of 2008 (H.R. 1084), Washington, DC: U.S. Government Printing Office, p. 6, section 5.

DoD Directive 3000.05 assigns responsibilities within DoD for planning and training to conduct stability operations. This directive supersedes previous ones and elevates stability operations to status equal to combat operations. In addition, for stability operations, U.S. military forces need to establish and maintain order when there is no civilian agency present. [54]

These directives take a pragmatic short and long term approach to SSTR operations. DoD Directive 3000.05 defines Stability Operations as "military and civilian activities conducted across the spectrum from peace to conflict to establish or maintain order in States and regions."[55] Further, it delineates military support to SSTR as "[DoD] activities that support [USG] plans for stabilization, security, reconstruction and transition operations, which lead to sustainable peace."[56] Moreover, according to the *SSTRO JOC*, military support to SSTR is a subset of stability operations (Figure 3).[57] Combined with DoD Directive 3000.05 the immediate goals of SSTR are to provide security, to restore essential services, and to meet humanitarian needs of the supported country. Therefore, the U.S. military will conduct SSTR operations in support of a broader USG effort that helps to establish order in an unstable, ungoverned, and contested environment. The long-term goals of SSTR are for the host nation to have an indigenous capacity for securing essential services, a viable market economy, rule of law, and democratic institutions.[58]

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[54] Department of Defense Directive. (2005). *Military Support for Stability, Security, Transition, and Reconstruction (SSTR) Operations*. (DoD Directive No. 3000.05). Washington, DC: U.S. Government Printing Office, p. 1-2.

[55] Ibid., p. 2.

[56] Ibid., p. 2.

[57] Joint Forces Command . (2006). *Military Support to Stabilization, Security, Transition, and Reconstruction Operations Joint Operation Concept (SSTRO JOC)*. (Version 2.0). Washington, DC: U.S. Government Printing Office, p. 7-8.

[58] DoD Directive #3000.05; p. 2.

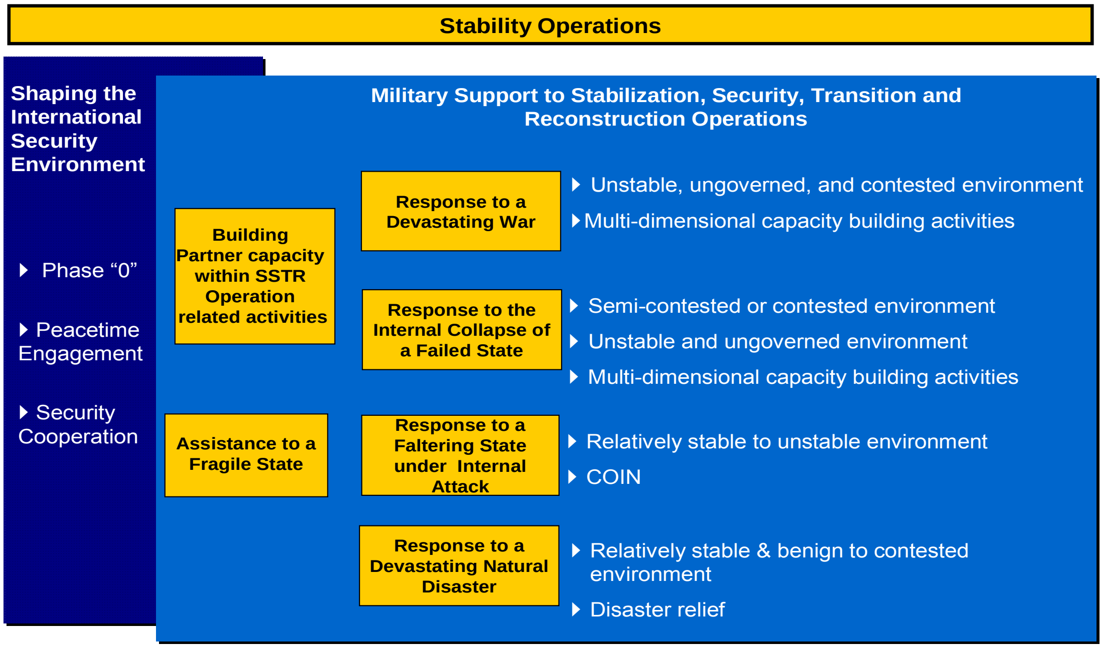

Figure 3. Military Support to SSTR Operations.

SSTRO JOC best defines describing the central elements (stabilization, security, transition, and reconstruction) of military support to SSTR operation:[59]

> **Stabilization** involves activities undertaken to *manage underlying tensions*, to *prevent or halt the deterioration* of security, economic, and/or political systems, to *create stability* in the host nation or region, and to establish the preconditions for reconstruction efforts.
>
> **Security** involves the *establishment of a safe and secure environment* for the local populace, host nation military and civilian organizations as well as USG and coalition agencies, which are conducting SSTR operations.
>
> **Transition** describes the process of *shifting the lead responsibility and authority for helping provide or foster* security, essential services, humanitarian assistance, economic development, and political governance from the intervening military and civilian agencies to the host nation. Transitions are event driven and will occur within the major mission elements (MMEs) at that point when the entity assuming the lead responsibility has the capability and capacity to carry out the relevant activities.

[59] SSTRO JOC, p. 2.

Reconstruction is the *process of rebuilding degraded, damaged, or destroyed* political, socio-economic, and physical infrastructure of a country or territory to create the foundation for longer-term development.

The primary focus of SSTR is to prevent states from failing, assisting governments recovering from natural disasters and aiding transitional government post conflict. Figure 4 illustrates the central idea for conducting SSTR operations, regarding how U.S. military efforts, combined with coalition militaries, USG agencies, and NGOs, use MMEs to facilitate the desired end state.[60] External forces provide direct assistance to "stabilize the situation and build self-sufficient host nation capability and capacity in [these] key areas".[61] Since satisfying the populace's basic needs is a common goal across multiple phases of joint campaigns and operations, this thesis will focus on the Navy and Marine Corps role in reconstruction of essential services.

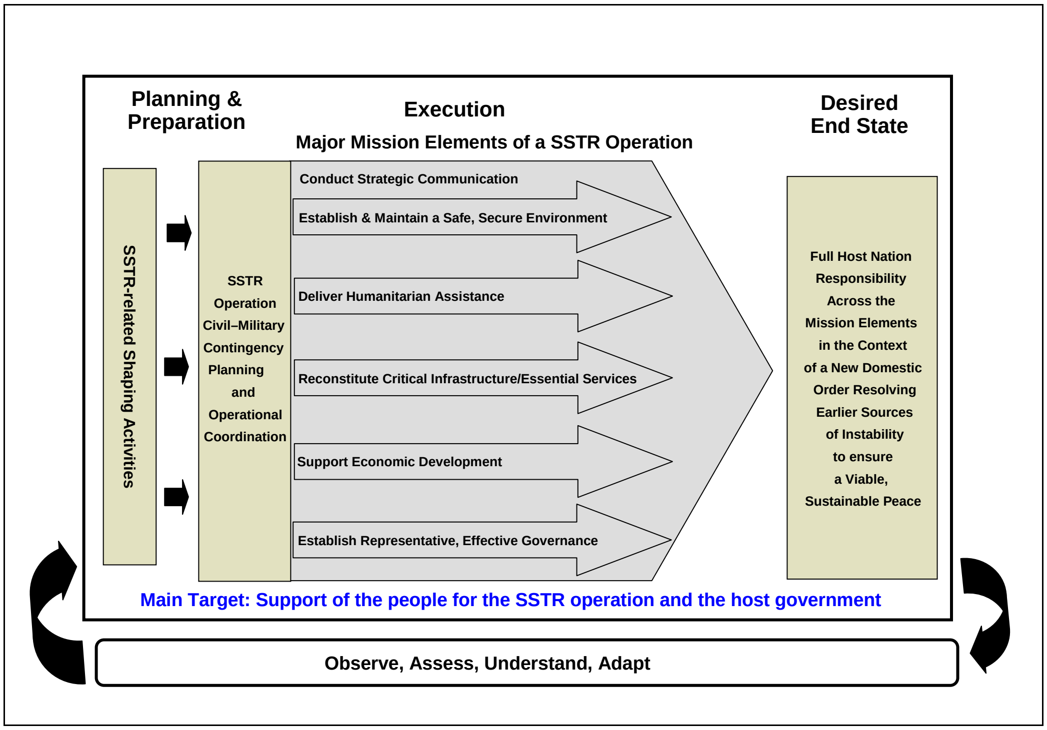

Figure 4. The Central Idea for Conducting SSTR Operations.

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[60] SSTRO JOC, p. 19-22.

[61] Ibid., p. iii.

E. CHARACTERISTICS OF AN OPERATIONAL ENVIRONMENT

Before a simulation can be defined, the characteristics of the military's *operational environment*—previously known as a battlespace—must be understood. Joint Publication 3-0 (JP 3-0) defines operational environment as:

> the composite of the conditions, circumstances, and influences that affect the employment of capabilities and bear on the decisions of the commander. It encompasses physical areas and factors (of the air, land, maritime, and space domains) and the information environment. Included within these are the adversary, friendly, and neutral systems that are relevant to a specific joint operation.[62]

The operational environment is composed of a series of related systems forming a complex whole.[63] These systems consist of nodes and links. "Nodes" can be a person, material or a facility, while a "link" is the behavioral or functional relationships between nodes.[64] Relationships can be described as a "command or supervisory arrangement that connects a superior to a subordinate, the relationship of a vehicle to a fuel source, or the ideology that connects a propagandist to a group of terrorists."[65]

Political, military, economic, social, information, and infrastructure (PMESII) are the six interrelated operational variables that joint planners use to analyze the operational environment[66] (illustrated in Figure 5[67]).

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[62] Joint Chiefs of Staff, (2008). Joint Publication 3-0 (JP 3-0), Joint Operations, Washington D.C.: U.S. Government Printing Office, Ch. 2, p. 20.

[63] Ibid., Ch 2, p. 23.

[64] Ibid., Ch 4, p. 4.

[65] Ibid.

[66] FM 3-0, Ch 1, p. 4.

[67] Figure is from JP 3-0, Ch 2, p. 23.

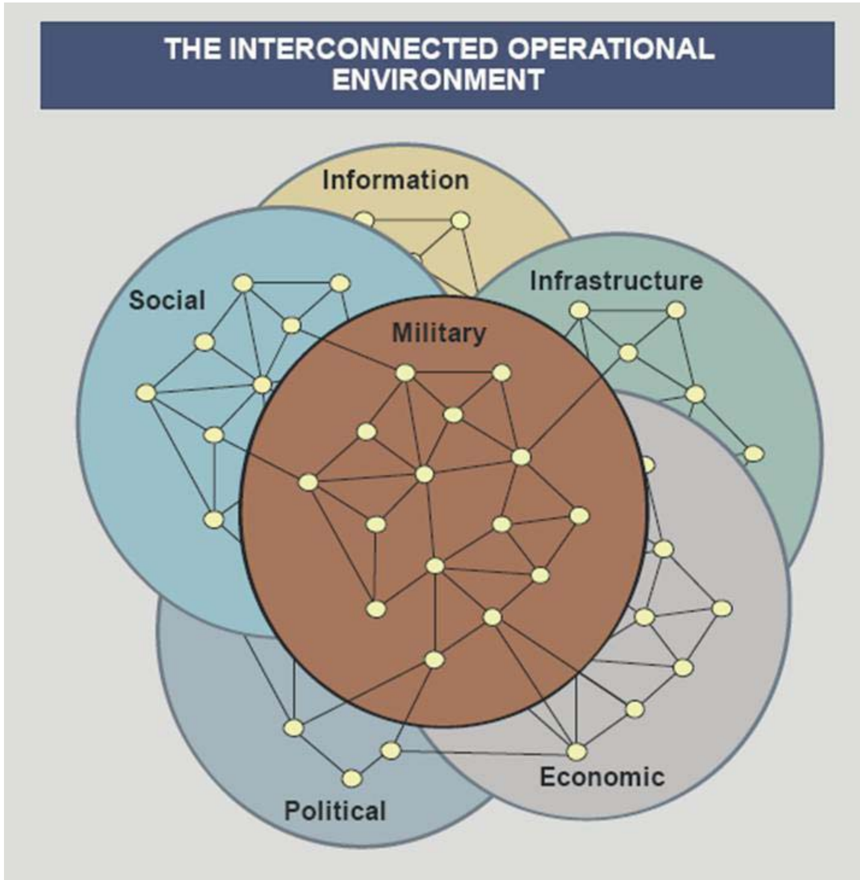

Figure 5. The Interconnected Operational Environment.

The objective of a PMESII conceptual model is to provide an understanding of how the operational environment reacts to external factors.[68] These influencers can either be friendly, neutral, or adversarial actors, and state or nonstate actors.[69] What is common is that all influencers employ instruments of national power—diplomatic, informational, military, and economic (DIME).[70]

68 JP 3-0, Ch 2, p. 23.

69 FM 3-0, Ch 1, p. 3.

70 Ibid., Ch 1, p. 3.

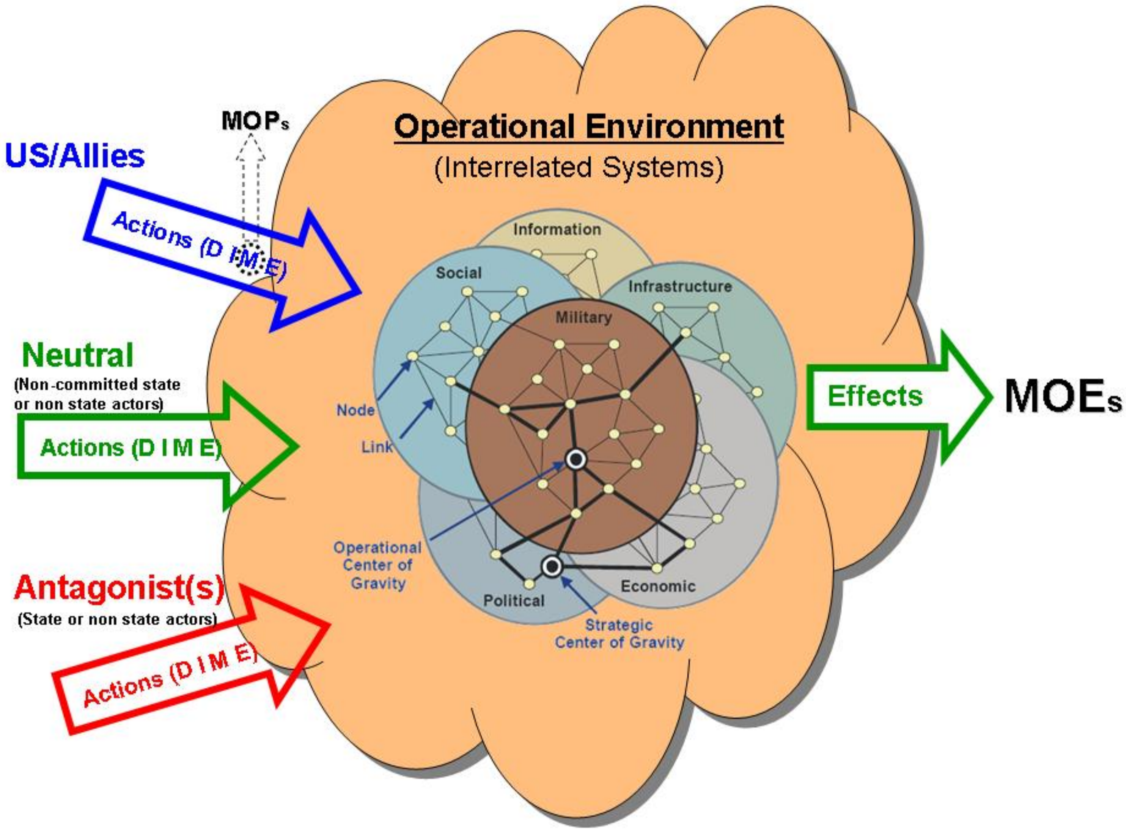

Figure 6. DIME PMESII Model

Together, the DIME PMESII model (as show in Figure 6) provides an interconnected picture that allows military analysts and decision makers to adopt a broader[71] perspective of any environment that U.S. forces and its allies may face. The intent of the DIME PMESII model is to provide a conceptual model for defining metrics that can measure the performance of outside forces and changes to the environment. Metrics to measure action and effects are Measures of Performance (MOPs) and Measures of Effectiveness (MOEs):

> MOPs measure how the system/individual performs its functions in a given environment (e.g., number of targets detected, reaction time, number of targets nominated, susceptibility of deception, task

[71] "Broader" in the sense that in the past U.S. military forces focused solely on the military system and only recently has begun to formally incorporate the other domains.

> completion time). It is closely related to inherent parameters physical and structural) but measures attributes of system behavior.[72]
>
> MOEs are a qualitative or quantitative measure of the performance of a model or simulation or a characteristic that indicates the degree to which it performs the task or meets an operational objective or requirement under specified conditions.[73]

Today, challenges to America's interest extend beyond the sphere of military operations.[74] To combat these dangers, military planning and execution must integrate government and nongovernmental agencies often in conjunction with multinational partners.[75] The DIME PMESII model may be incomplete;[76] nonetheless, this model is derived from policy and is a foundation to build a better solution. As such, it provides an excellent starting point for deriving requirements for simulations supporting analysis and training of Navy and Marine Corps operations and capabilities in restoring essential services.

F. DEPARTMENT OF THE NAVY CAPABILITY AND ITS EFFECTS ON RESTORATION OF ESSENTIAL SERVICES

In an April 2007 report to Congress on the implementation of DoD Directive 3000.05, the Secretary of Defense stated that the DoN established the Naval Expeditionary Combat Command (NECC). The objective of NECC is to adopt capabilities for stability operations. These missions include "Explosive

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[72] Under Secretary of Defense for Acquisition Technology (January 1998), DoD Modeling and Simulation Glossary, Washington D.C.: Department of Defense, p. 136, and see also IEEE STD 610.3 (references (b) and (c)).

[73] Ibid.

[74] Colonel Jack Kem (2007). Understanding the Operational Environment: The Expansion of DIME, *Military Intelligence Professional Bulletin (MIPB)*, p. 1, Retrieved July 17, 2008, from http://www.universityofmilitaryintelligence.us/mipb/article.asp?articleID=578&issueID=45.

[75] Colonel T.X. Hammes. (2007). Fourth Generation Warfare Evolves to Fifth Generation, *Military Review*, p.20. Accessed February 20, 2008, from http://www.dreaming5gw.com/2007/05/colonel_hammes_enters_the_fift.php.

[76] JP 3.0 does not use the acronym PMESII, but spells out "political, military, economic, social, information, infrastructure, and others" for the number of systems that are in the operational environment. Further, DIME is not explicitly formed as inputs to the operational environment but stated as actions taken by actors.

Ordnance Disposal (EOD), Expeditionary Medicine, Mobile Security Squadrons, Naval Construction Battalions (Seabees), and an Expeditionary Training Command," as well as the establishment of a new Maritime Civil Affairs Group (MCAG) consisting of two squadrons. The same report called for the Marine Corps to create the Center for Irregular Warfare, the Center for Advanced Operational Culture Learning (CAOCL), and an SSTR section within its headquarters[77]: "These organizations will ensure effective advocacy for SSTR issues within the Marine Corps and proponency for Marine Corps SSTR issues in the Joint and Interagency arenas."[78] Similar to the Navy, the Marine Corps has a civil affairs group that supports the Marine Expeditionary Force (MEF) during all phases of the operational spectrum. Civil affairs plan, coordinate, and conduct activities among the MEF, U.S. non-military agencies, NGO's, a host nation's military, and civilian forces to maximize support for landing force operations.

The Navy-Marine Corps team is situated perfectly to support SSTR Operations because of their quick response time and limited support requirements in the indigenous region. In addition, since the Navy has organic command and control, their platforms can provide a less overt assistance while preserving the host nation's legitimacy. Further, Navy-Marine Corps teams are equipped to be entirely self-sufficient. If the situation changes and the DoN is no longer desired or required, the team can redeploy rapidly. Since many Navy and Marine units are forward deployed, these forces can arrive at any location in the world within days to support an SSTR Operation.[79]

The DoN is uniquely qualified and positioned to overcome the challenges that arise from water-stressed regions. Specifically, the Navy has the capability to produce, store, transport, and distribute water anywhere around the world.

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[77] Department of Defense. (2007), *Report to Congress on the Implementation of DoD Directive 3000.05 Military Support for Stability, Security, Transition and Reconstruction (SSTR) Operations*, Washington, DC: U.S. Government Printing Office, p. 6-7.

[78] Ibid.

[79] Donna Miles (May 8, 2008). Gates: U.S. Military Ready to Help; Ships, Air Support Staged. *American Forces Press Service*. Retrieved August 4, 2008, from http://www.defenselink.mil.

Each large deck ship, carrier or amphibious and large maritime cargo vessel can produce up to 90,000 gallons of potable water each day.[80] American naval vessels have organic desalination plants (either Reverse Osmosis purifiers or Flash Evaporators) that remove salt from ocean water to purify it. Due to pollution, the desalinization process needs to take place away from populated littoral waters. The closer to shore, the more bromine is required in the water, and too high of a level can be toxic to people.[81]

Primary limitations in capabilities are storing and transporting the water from ship to shore. Regarding storing the water, there are two constraints. Large decks, which comprise the core of forward deployed fleets, and maritime cargo ships can only carry 450,000 gallons of fresh water on pallets.[82] Secondly, containers are small sized and finite in number of individual containers. They also require manual labor to fill. After Hurricane Katrina struck New Orleans, the USS Harry S. Truman had more than 20,000 bottles of water ready for transportation ashore.[83] During the last Asian tsunami relief operation in Indonesia, the USS Abraham Lincoln distributed over 5,000 gallons of water at the start of the operation.[84] Sailors from the Lincoln's Reactor Department filled and stacked 800 five-gallon containers in 45 minutes.[85] According to the crew, they were limited by the number of containers on-hand and the weight limit of the

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80 Vince Little (December 31, 2004). 3rd MEF to lead PACOM disaster-relief, humanitarian efforts in Southeast Asia. *Stars and Stripes*. Accessed August 4, 2008, from http://www.stripes.com.

81 Department of the Navy. (2005). Manual of Naval Preventive Medicine, Chapter 6, Water Supply Afloat (NAVMED P-5010-6). Washington, DC: Bureau of Medicine and Surgery.

82 Vince Little (January 12, 2005). U.S. military hauling food, water, clothing, manpower to Southeast Asia. *Stars and Stripes*. Retrieved August 4, 2008, from http://www.stripes.com.

83 Warhips International Fleet Review (September 6, 2005). Web Special – Hurricane Katrina. *Global Naval News*. Retrieved August 4, 2008, from http://www.warshipsifr.com/hurricane_special1.html.

84 Douglas Shulz (January 1, 2005). Lincoln provides drinking water to tsunami victims. *USS Abraham Lincoln Public Affairs*. Retrieved August 4, 2008, from http://www.c7f.navy.mil/news/2005/january/17.htm.

85 Ibid.

transporting helicopters.[86] Heavy lift aircraft, like a CH-53 A/D/E Sea Stallion, can carry between 8,000-26,000[87] pounds of cargo. Medium lift aircraft, such as a CH-46 D/E Sea Knight can only carry 5,000 pounds of cargo.[88] In addition to these limitations, the main limiting factor is the finite number of storage containers (especially since the ships can make more water).

After marines and sailors fill up clear plastic water bladders, these critical supplies must be distributed to the populace. To maximize efficiency, these bladders are aggregated into shipments that are more easily transported. As an example, during the humanitarian assistance operation to aid cyclone-stricken Burma, the USS Essex manufactured a fresh water distribution system that mirrored a miniature farming irrigation system. They filled water bladders and stored them in large boxes for transport.[89] For the military final distribution ends with the transportation of the water to the entity it is supporting. This could be another U.S. agency or NGO leading the humanitarian operation. It can also be an indigenous agency to the region or directly to the populace. An issue that is highly complex and sometimes overlooked is the effect of what agency gets credit for distributing the water to the populace. Water in itself is a resource that can equate to power and legitimacy.[90] If the distribution is poorly managed, then the operation or host nation legitimacy can be undermined.

[86] *USS Abraham Lincoln Public Affairs.*

[87] Information from the Rotary Wing and Tilt-Rotor page of the Warfighter's Encyclopedia Website https://wrc.navair-rdte.navy.mil/warfighter_enc/aircraft/Helos/Stallion.htm, see also the United States Marine Corps' Marine Aviation website http://hqinet001.hqmc.usmc.mil/AVN/documents/aircraft/rotarywing/ch53.htm.

[88] Information from the Helos page of the Warfighter's Encyclopedia Website https://wrc.navair-rdte.navy.mil/warfighter_enc/aircraft/Helos/Cknight.htm.

[89] Ryan Wicks (May 11, 2008). Marines, Sailors Prepare for Possible Operations in Burma. *American Forces Press Service*. Accessed August 4, 2008, from http://www.defenselink.mil.

[90] JP 3.0 states in Appendix A that legitimacy bestowed upon a local government through the perception of the populace that it governs. Humanitarian and civil military operations help develop a sense of legitimacy for the supported government. During operations in an area where a legitimate government does not exist, extreme caution should be used when dealing with individuals and organizations to avoid inadvertently legitimizing them.

The most effective SSTR operations have both short and long-term solutions for the host nation. Although the Navy-Marine Corps team are extremely helpful when called upon to assist a state in crises, it is critical when conducting an SSTR operation to restore the host nation's infrastructure. Water originating from a U.S. naval vessel only provides a short-term solution. The host nation requires reconstruction of a water supply system for which the Seabees have a proven history of success.[91] Along with the Seabees, Maritime Civil Affairs squadrons are responsible to Geographic Combatant Commands for providing civil affairs support, which includes Humanitarian Assistance and Disaster Relief, Non-Combatant Evacuation Operations, Refugee Operations, and restoration of infrastructure in the aftermath of a natural disaster. As policy and doctrine adapts to the evolving nature of SSTR operations, the military must plan and train for these complex situations. Simulation technology can assist the DoN in addressing these analytical and training needs.

From these examples, the need to represent capabilities to create, store, and distribute essential services for military planning and training is clear. The next sections describes how M&S can assist the analyst and trainer in this area.

G. MODELING AND SIMULATION SUPPORT TO ANALYSIS AND TRAINING FOR RECONSTRUCTION OF ESSENTIAL SERVICES

As the Operational Environment becomes more complex, political and military decision makers need an analytical process that examines as many known variables as possible. In the past, the field of Operational Research (OR) has used simulations to help provide an estimate of outcomes. These simulations are based on first establishing a well-understood underlying mathematical model. Lanchester Equations are a prime example of the application of these models. Deterministic and stochastic Lanchester models are based on equations that are calculable. The output of deterministic models is, as

[91] Dan Cook (2008). Focus on Africa. *United States Navy Seabees Magazine.* Washington, DC: Naval Facilities Engineering Command, p. 3.

the name implies, “determined” once the set of input quantities and relationships in the model have been specified.[92] Stochastic models provide potential outcomes by allowing random variation in its input and computations.[93] The key concept when selecting a simulation is its intended purpose. For analysts and instructors, simulations are not intended to be “the” answer, but are instead intended to assist. Therefore, the simulation must be evaluated against the analyst’s requirements or the instructor’s training objectives to determine an accurate assessment of the simulation’s usefulness.

In 1914, F. W. Lanchester published *Aircraft in Warfare: The Dawn of the Fourth Arm* that describes the basic Lanchester Equations predicting force levels in a combat engagement with single term differential equations for any military platform.[94]

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92 Averill Law and David Kelton (2000), *Simulation Modeling and Analysis*, 3rd edition, Boston: McGraw-Hill, p. 6.

93 Ibid., p. 6.

94 Lanchester-type attrition models refer to the set of differential equation models that describe changes, over time, in the force levels of combatants and other significant variables that describe the combat process. James Taylor (1983), *Lanchester Models of Warfare*, Vols. 1 and 2, Arlington, VA: Operations Research Society of America, p. 28.

	Square Law	Linear Law
Differential Equations	$\frac{dx}{dt}=-ay\,,\frac{dy}{dt}=-bx$	$\frac{dx}{dt}=-axy\,,\frac{dy}{dt}=-bxy$
State Equation	$b(x_0^2-x(t)^2)=a(y_0^2-y(t)^2)$	$b(x_0-x(t))=a(y_0-y(t))$
Who wins in a *Fight to the finish?*	$\frac{X_o}{Y_o}>\sqrt{\frac{a}{b}}\therefore Xwins$ $\frac{X_o}{Y_o}<\sqrt{\frac{a}{b}}\therefore Ywins$ $\frac{X_o}{Y_o}=\sqrt{\frac{a}{b}}\therefore Draw$	$\frac{X_o}{Y_o}>\frac{a}{b}\therefore Xwins$ $\frac{X_o}{Y_o}<\frac{a}{b}\therefore Ywins$ $\frac{X_o}{Y_o}=\frac{a}{b}\therefore Draw$
How long will it take in a *Fight to the finish?*	If y wins: $T=\frac{1}{2\sqrt{ab}}\ln\left(\frac{\sqrt{\frac{a}{b}}y_o+x_o}{\sqrt{\frac{a}{b}}y_o-x_o}\right)$ If x wins: $T=\frac{1}{2\sqrt{ab}}\ln\left(\frac{\sqrt{\frac{b}{a}}x_o+y_o}{\sqrt{\frac{b}{a}}x_o-y_o}\right)$	If y_{wins} $T=\frac{1}{ay_o-bx_o}\ln\left(\frac{y_o-\frac{b}{a}(x_o+Threshold)}{Threshold\,\frac{y_o}{x_o}}\right)$ If x_{wins} $T=\frac{1}{bx_o-ay_o}\ln\left(\frac{x_o-\frac{a}{b}(y_o+Threshold)}{Threshold\,\frac{x_o}{y_o}}\right)$
How many forces left in a *Fight to the finish?*	If X wins: $x(t)=\sqrt{x_o{}^2-\frac{a}{b}y_o{}^2}$ If Y wins: $y(t)=\sqrt{y_o{}^2-\frac{b}{a}x_o{}^2}$	If X wins: $x(t)=x_o-\frac{a}{b}y_o$ If Y wins: $y(t)=y_o-\frac{b}{a}x_o$

Table 1. Lanchester Equations.[95]

After the initial publication of these equations, adaptations evolved.[96] Since every model is a representation of the real world and not completely accurate, the choice of which Lanchester Equation to use changed with the needs of the

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95 From the differential equations and state equations, mathematical manipulations of the equations answer certain combat related questions. X and Y represent the number of forces on two opposing sides. x_0 and y_0 represent the number of forces at the beginning of the combat engagement. a and b represent the combat effectiveness of the respective side. T represents time, and $x(t)$, $y(t)$ represent how the forces levels change over time. $Threshold$ represents the number of forces that a side is considered to have lost the engagement.

96 Several extensions or enrichments to Lanchester have been explored. Examples are the Hembold Equations, Morse and Kimball Law, Mixed Combat Equations, adding range dependent attrition parameters, or reinforcement parameters. Each of these extensions added another level of complexity to the basic Lanchester, but still has the same characteristics of solvable systems of differential equations.

analyst. As the equations became more complex, the analyst turned to simulation to gain further insights from the chosen equation.

Today, many of the currently validated and accredited kinetic simulations have Lanchester Equations as the basis of determining force levels. Although only the Battle of Iwo Jima force levels has ever been proven to follow the rules of Lanchester Equations[97], analysts and instructors continue to find extremely useful Lanchester's simplified kinetic warfare conceptual models. However, a wicked problem, like modeling military support to SSTR Operations, should not be done with a simplistic view of its non-kinetic interactions. Lanchester Equations had limited success because they described a specific and isolated situation on the battlefield. Yet, this was at the expense of disregarding intangibles of war like leadership, morale, and fatigue. Since the variables within the operational environment are deeply interrelated, a well-defined "Lanchester style" equation to model SSTR is far from being realized. So in order to begin to solve this dilemma, military support to SSTR Operations must be divided into small solvable problem sets that can provide insights to the military decision maker. This leads to consideration of modeling approaches that deal with representation of small-scale elements in the environment that have local interactions that can cascade into observable larger-scale macro-level behaviors. Such approaches are discussed in more detail later in this thesis (see Chapter V).

1. How Can Simulation Assist the Analyst?

In today's political environment, the consequences for failure could be so severe that operational success is required on the first attempt. Simulations can minimize problems by creating a virtual laboratory in which civilian and military decision makers can experiment with variables in an operational environment (See Figure 7).

[97] J. H. Engel (1954). Verification of Lanchester's Law. *Journal of the Operations Research Society of America*, volume 2 (issue 2), p. 163-171.

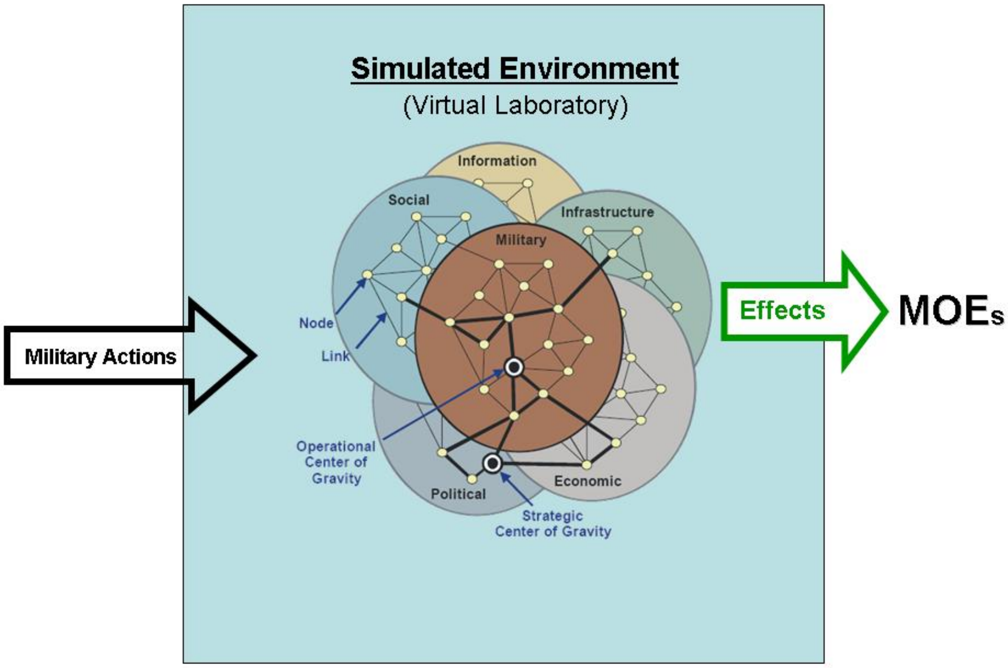

Figure 7. Simulating the Operational Environment

It is well understood that "all models are wrong, but some models are useful."[98] Models are approximations of reality whose level of utility depends on design and use. The simulation must be based on well-defined requirements in order to be a useful simulation. Although simulations are a simplification of reality, they provide the decision maker a means of exploring root causes and effects that are relevant to the problem. As an example, if a useful water infrastructure and population needs simulation was added to an existing military kinetic simulation, then an analyst can pose the question "What are the first, second, and third order effects on the population if a water plant is destroyed?" (See Figure 8). This data would provide the leadership information to plan several courses of action. Yet, the human element often introduces to the problem space wide variability. Simulations cannot always provide precise answers, but must always provide insight.

[98] George Box (1987), *Empirical Model-Building and Response Surfaces*, Hoboken: Wiley, p. 424.

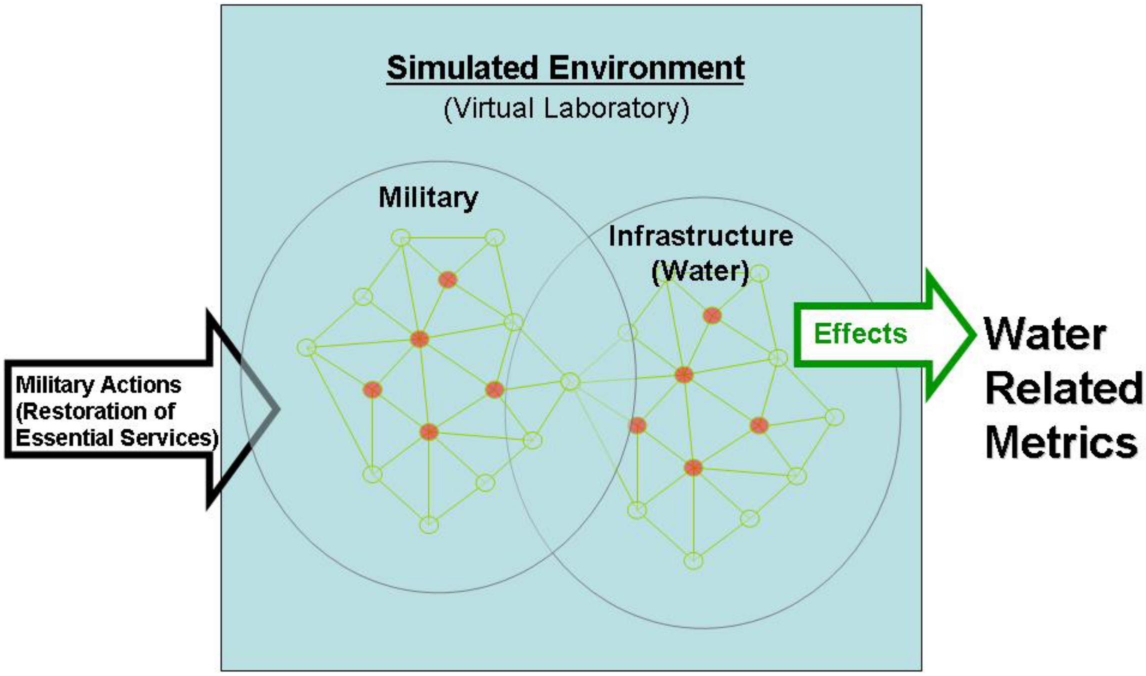

Figure 8. Infrastructure (Water) System added to a Kinetic Military Simulation

In general, models fall on a variability spectrum[99], and where they lie on this spectrum determines several critical characteristics that can affect their utility. Several models have near zero variability, like Physics based models, where the results are easily replicable over an infinite time horizon and provide near 100% accuracy. In contrast, different weather models can have very different outcomes. Nonetheless, these models still provide useful information providing insights to weather experts for forecasting future possibilities. Forecasters encounter a dilemma between balancing prediction uncertainty with the forecast timeline. Increasing a forecast timeline amplifies the model's inaccuracy. In addition, models with high variability, lead individual experts to derive different conclusions from identical simulation outputs. This is not the case with a near zero variability model, where the analytical process is so certain that the entire process can be automated, thereby removing the human from the

[99] Variability spectrum means the spread of data points that are provided. In statistics, the variation is what is important and helps define the unknown and derive a best estimation of what is known. De Veaux, Velleman, and Bock (2005), *Stats: Data and Models*, Boston: Pearson.

loop. Simulating the water supply effect on a population is similar to predicting the weather, in that the model involves volatile factors – such as the human element – that need interpretation. Simulation is an excellent tool for generating a range of possible outcomes for interpretation by skilled and knowledgeable analysts.

2. How Can Simulation Assist the Trainer?

An instructor can use a simulation as a tool to accomplish training objectives that enlighten military professionals, while exposing them to a new environment, without worry of a wrong decision's catastrophic repercussion. If the simulation adequately represents the operational environment, then the military professional can experiment and learn how first, second, and third order effects of military actions affect the populace, when consequences are virtual. As an example, one training requirement for command post exercises is that a staff be able to control civil unrest while conducting restoration operations of basic public services including police functions, water, electricity, garbage, and basic medical care.[100] However, an expert is required to counteract negative training when the model mismatches the real world.[101] If the simulations are valid, military professionals will operate in a virtual setting that represents future possibilities.

H. FIGHTING GARBAGE IN, GARBAGE OUT

For any simulation to have relevance, it must have a solid foundation in data. Data collection methodologies that have been identified as reliable and

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[100] Michael Spirtas, et al (2008), *Department of Defense Training for Operations with Interagency, Multinational, and Coalition Partners*, Arlington, VA: RAND Corporation, p. 11-14, 77.

[101] William Yates and James McDonough (2006), A More Realistic Command Post Exercise, *Marine Corps Gazette*, volume 90 (issue 9), p. 12.

necessary include statistical analysis, utilization of the subject matter experts (SMEs), surveys or polling data, and content analyst.[102] Each of these techniques is described below.

1. Statistical Analysis

Statistical Analysis is an arithmetic method that uses a variety of statistics regarding security, standard of living, and economic development to assess a situation.[103] In social science it is sometimes difficult to identify reliable statistics; however, analysts are willing to use statistics that are objective. Typical data found in social sciences, often considered useful, can have values of R^2 as low as 0.25.[104] The intent for the analyst is to understand how each variable interacts and capture why something happened rather than what result may occur. This differs from "hard" science, like physical and medical sciences, where R^2 values of 0.60 are accepted, and in some cases, R^2 values greater than 0.90 can be found.[105] This will require a paradigm shift for analysts who are used to dealing with statistics that are two and three times more correlated. More uncertainty will have to be accepted with the input of social science data.

2. Subject Matter Experts

The second methodology entails utilizing SME opinion that entails a pool of independent, knowledgeable, and experienced experts to assess an issue.[106] Despite the introduction of subjectivity, evaluation criteria and data gathering tactics dictate the reliability of the findings and if they can be replicated. Since

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[102] According to a draft Measuring Progress in Conflict Environments (MPICE) metrics framework (draft). MPICE is a collaborative project by the United States Institute of Peace, the United States Army Corps of Engineers, and the United States Army Peacekeeping and Stability Operations Institute.

[103] Ibid., p. 5.

[104] Anderson, Sweeney, and Williams (2007), *Statistics for Business and Economics*, Stamford: Cengage Learning.

[105] Ibid.

[106] MPICE, p. 5.

the SMEs have greater knowledge and personal experience, they have the tools to provide analysts with information for sound qualitative judgments. Unfortunately, many critics will point out that each SME's views are merely opinion. Further, biases, political agendas, and individual experiences cloud the certainty of accuracy. However, a process that can quantify qualitative data, adds another dimension to a simulation.[107] This process of extracting quantitative data from SME's qualitative information is still in its infancy. Yet, this information is too valuable to exclude, and in some cases, is the only data available.

3. Surveys

Conducting surveys or polls, though time consuming, are useful in analyzing a society's views. This methodology helps to provide a general overview of societal morays and conveys more confidence in findings. Furthermore, it can be conducted on a large number of people. However, the design and delivery of the surveys are a critical factor that can counteract the benefits. In addition, the sample size must be large enough and randomly selected to preserve the representative sample criteria that experiments demand. If either of these pitfalls are not avoided, the simulation will not generate reliable results.

4. Content Analysis

Content analysis is the method that has the smallest overhead but is the most time consuming. It is the process of researching open source information. This includes, but is not limited to, media publications, reputable internet BLOG

[107] The USMC Operations Analysis Division conducted an Irregular Warfare study in which two SMEs were consulted to test this process. They found that cultural SMEs are non-quantitative thinkers and were reluctant to put numbers as representations of their opinions. However, the process did extract numbers in a very specific test case that proved to be a useful first step in identifying how and to what extent SME data collection can be accomplished. The authors of the experiment acknowledge this approach may have limitations but is worth further investigation as the process matures. (Mr. Leroy Jackson, personal communication, July 30, 2008).

sites, and NGO publications. Its main advantage is that the information is easily accessible. The drawback is in choosing which publication to survey.[108] The analysts can be overwhelmed under the enormous amount of information in existence. With the current tools, this leads to labor-intensive efforts to glean the critical gems of relevant data. Certain technologies, like artificial intelligence data mining, may eventually alleviate this problem, but no tool currently exists.

I. SUMMARY

This chapter provided further background and description of the nature of SSTR Operations, with description of Naval capabilities to support restoration of essential services; specifically, water. The chapter discussed the value of modeling and simulation to military analysts and trainers addressing the need for better understanding of this area of operations, and described several techniques for ensuring the model is supported by credible data. On the basis of this background, the next chapter specifies requirements for modeling and simulation of restoration of essential services.

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[108] MPICE, p. 5.

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III. REQUIREMENTS FOR MODELING RESTORATION OF ESSENTIAL SERVICES

Much more important are rates and ratios. NGOs stress obtaining cognizance of the distribution of the entire population, not just focusing on the convenient 'average.

-- MORS Workshop[109]

A. INTRODUCTION

Before current M&S capabilities can be evaluated or before new M&S capabilities can be designed and developed, the fundamental software requirements must be identified. This chapter lays out the top-level requirements that need to be met in M&S to support analysis and training.

B. MODELING AND ARCHITECTURE REQUIREMENTS

The Office of the Secretary of Defense (OSD) sets policy that requires all services within DoD to plan and train for SSTR Operations.[110] This includes gaming the red team, interoperating with other agencies, and incorporating social sciences.[111] Doctrine has five – necessary but not sufficient – requirements for operations to restore restoration of essential service: averting humanitarian crises; critical inputs to social relationship models; maintaining the security of essential services; meeting the international standard for disaster relief; and collaborating with civilian organizations. Simulations must provide representations of these operations.

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[109] Col Gregory Reuss and COL George Stone (Chairs). (25-27 October 2005). Proceedings from *MORS Workshop: Agent-Based Models and Other Analytic Tools in Support of Stability Operations*. McLean, Virginia, p. 13.

[110] DoD Directive No. 3000.05, p. 1.

[111] Ibid., p. 3-5.

1. Averting Humanitarian Crises

U.S. forces must provide consumable resources in a timely manner to avert a Humanitarian Crisis. To simulate such a crises, a resource model needs to capture production, storage, distribution and transportation of needed commodities. The commodities need to be simulated as perishable items that are consumed. The simulation needs to be componentized[112] and account for how timeliness of delivery impacts success.

2. Critical Inputs to Social Relationship Models

The simulation data needs to accept social models that measure the legitimacy of the host nation's government and person-to-person relationships, as well as provide social models access to its internal data. The person-to-person relationships would include relations between each other, the populace and its government, and populace and U.S.. Since social theories vary, this essential service simulation needs provide an open framework where different social models can be readily integrated. The data will be statistics that measure the effectiveness of averting humanitarian crises and data affecting person-to-person relationships.

3. Maintaining the Security of Essential Services

In order to simulate maintaining security, the simulation has to represent aspects of essential services that are vulnerable to attack or degradation. Instead of creating a new warfare simulation, it is more efficient for this simulation to have an open architecture[113] that integrates an existing kinetic simulation.

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112 "Componentized" in this case means that the process of production, storage, distribution, transportation of one organization can feed into another organization's similar process or end with delivery to the final node.

113 "Open architecture" in this case means that the simulation allows for the addition, upgrade and exchange of components.

4. Meeting the International Standard for Disaster Relief

For this simulation to be valuable, the parameters that guide the measures of success must include principles from national and international disaster response agencies specified in existing publications.[114]

5. Collaborating with Civilian Organizations

This simulation needs to be an open architecture and an unclassified framework to integrate with all U.S. agencies, foreign governments and security forces, International Organizations, NGOs, and members of the Private Sector.[115] With an open architecture and an unclassified framework, other organizations can develop software tools that integrate with this simulation for combined training and analysis.

C. SUMMARY

The identified modeling and architecture requirements provide a basis for subsequent conceptual modeling, design, and implementation of the model. Before proceeding to these development steps, however, it is also important to identify requirements relating to measures of performance and measures of effectiveness that the model needs to be able to compute. These measurement requirements are identified in the next chapter.

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[114] One such document is *The Sphere Projects: Humanitarian Charter and Minimum Standards in Disaster Response* where 400 organizations and 80 countries contributed to the minimum standards and key indicators.

[115] Directed by DoD Directive No. 3000.05, p. 3.

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IV. METRICS FOR RESTORATION OF ESSENTIAL SERVICES

Not everything that can be counted counts; and not everything that counts can be counted.

-- Albert Einstein

A. INTRODUCTION

To be an effective tool for analysis and training, the model of restoration of essential services needs to be able to generate meaningful measures that can be used for evaluating progress in the conduct of those missions. This chapter discusses what constitutes well-defined measures, explores metrics relating to restoration of essential services, and identifies specific computational requirements (measures of performance and measures of effectiveness) for the proposed model.

B. WELL-DEFINED MEASURES

Publications used for operational test and evaluation and organizations, like the *Defence Science and Technology Laboratory, Ministry of Defence, United Kingdom*, provide insights for guiding metric requirements. Their metrics govern a variety of tools used by Operations Research analysts. Some of these criteria are not relevant to computer simulations. Three criteria identified have particular applicability to the current concern: commander's intent, mathematical properties, and utility. Each of these are discussed below.

The first criterion encompasses the commander's intent of the simulation from the "top-down". In this category, metrics are evaluated on relevancy—both to the indigenous population[116] and to the mission.[117] If the metric does not

[116] The Defence Science and Technology Laboratory, Ministry of Defence, United Kingdom has developed a Code Of Best Practice for use of Measures of Effectiveness (MOE) in Support of Operations in which it explains that MOEs should be culturally and locally relevant. MORS Workshop, p. 12.

satisfy basic functions such as these, then the measures will not provide information that is useful to the military decision maker. Overall, the metric needs to answer the question "How is this metric helping to accomplish the mission?"

Second is the "bottom up" category that captures many of the "mathematical" properties of good MOEs. The entire list of MOEs needs to be complete in its coverage and mutually exclusive.[118] "Complete" means that all of the changes to the environment are reflected in at least one MOE, and no environmental effect is left out. "Mutual exclusivity" complements "completeness," in order to ensure that no environmental effect is double counted. This will ensure that the MOEs have low correlation and will provide unique and useful information. In addition, the output metrics should be sensitive to input data[119], so that the analyst does not inadvertently add inconsequential variables. If changing input data does not change the output metric, then the information the metric provides may not be useful. Lastly, most designers agree that all metrics should be measurable—either quantitative or qualitative.[120] The challenges with encapsulating social science qualitative data have been discussed and warrant close examination. However, if the designer follows these criteria, then metrics will hold up to mathematical scrutiny and will lend valuable information to statistical analysis.

In between the two previous criteria is a category that concerns how much utility the metric will have for a military decision maker. All of the criteria in this category deal with conveying the metric designer's intent to the basic users. First, the metric is evaluated on how well it can be explained and how

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117 "MOEs should be directly related to the missions of the system and to the design and other critical issues." Roger Stevens (1979). *Operational Test and Evaluation: A Systems Engineering Process*. (T&E) New York: John Wiley and Sons, Inc. p. 55.

118 Ibid.

119 MORS Workshop, p. 12.

120 Ibid.

comprehensible the definition is.[121] If the explanation is unclear, then it will have limited utilities for the customer. Furthermore, the definition needs to eliminate ambiguity.[122] The metric should have contextual meaning to the user.[123] Metrics without context will probably be discounted. When defining metrics, human user utility must be considered or the data will be in danger of being discounted or improperly utilized.

C. ESSENTIAL ELEMENTS OF ANALYSIS (EEA)

The System Engineering's EEA Process for Operational Test and Evaluation (OT&E) provides metrics for restoration of essential services such as water. Its methodology is derived from military doctrine and NGO publications. EEA meets an objective by subdividing a "critical issue," defined as a system whose capabilities, operational effectiveness and other aspects are controversial, into measurable parts and collecting quantitative and qualitative data[124] Developing an EEA begins with the identification of sub-objective questions for the restoration of the essential element.[125] The military decision maker can then evaluate each sub-objective question on the basis of a specific measurement or qualitative judgment during the simulation. The process of evaluation is repeated until the critical issue and every subsequent question can be answered. This final step may be as simple as rewording the question or expanding the definition to fit the criteria for creating a "good" MOE.[126] (See Table 2). It is important to subdivide the critical issue in a manner that prevents ambiguity and answers the decision maker's question. A definition that is too narrow may lead to the rejection of an acceptable solution for frivolous reasons.

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[121] MORS Workshop, p. 12.

[122] T&E, p. 55.

[123] MORS Workshop, p. 12.

[124] T&E, 18, 49.

[125] Ibid., p. 50.

[126] As defined in Section B of this Chapter.

Utility of Metric	Mathematical "Bottom-Up"	Commander's Intent "Top-Down"
• Context Meaning	• Mutually Exclusive	• Mission Relevant
• Precise	• Complete	• Relevant to Population
• Well Explained	• Sensitive	
• Comprehensible	• Measurable	

Table 2. Necessary Characteristics of Good MOEs

D. EEA PROCESS FOR RESTORATION OF ESSENTIAL SERVICE - WATER

This thesis answers one of the critical issues posed by the Navy Research Lab (NRL) and Naval Operations Assessment Division (N81), "What is the impact of disruption and/or enhancement of [water system] infrastructure on population's [water needs]?"[127] Army doctrine and NGO publications divide this question into sub-objectives. The Army categorizes the restoration of an essential service into five elements; however, it stops at simply providing an element like food and water and fails to cover the difficulties associated with distribution, disruption of these efforts and the subsequent reaction of the population.[128] For this reason, the Red Cross' *Sphere Project* provides the needed amplification to fulfill the simulation requirements identified in Chapter III, to avoid a humanitarian crisis and meet international standards for disaster relief. The Red Cross provides three water supply standards, quantity, quality and water use that are not part of doctrine. As an example, the water quantity key indicators are as follows:

- Average daily water use for drinking, cooking and personal hygiene in any household is a minimum 15 litres per person
- The maximum distance from any household to the nearest water point should be 500 metres.
- Queuing time at a water source must be less than 15 minutes
- Filling a 20-litre container should average three minutes

[127] Posed at the DIME- PMESII Modeling Requirements Workshop that took place on 5 December at the Johns Hopkins University War Analysis Laboratory (JHU/APL) in Laurel, Maryland: (R. Hillson, personal communication, December 11, 2007).

[128] FM 3-07 is currently being re-written to provide depth as well. *FM 3-0*, p. 3-13.

- Ensure maintenance of water sources and systems to keep water available on a regular basis[129]

Guidance notes further amplify key indicators and can pinpoint root causes of problems. The entire process above can be visualized in Figure 9.

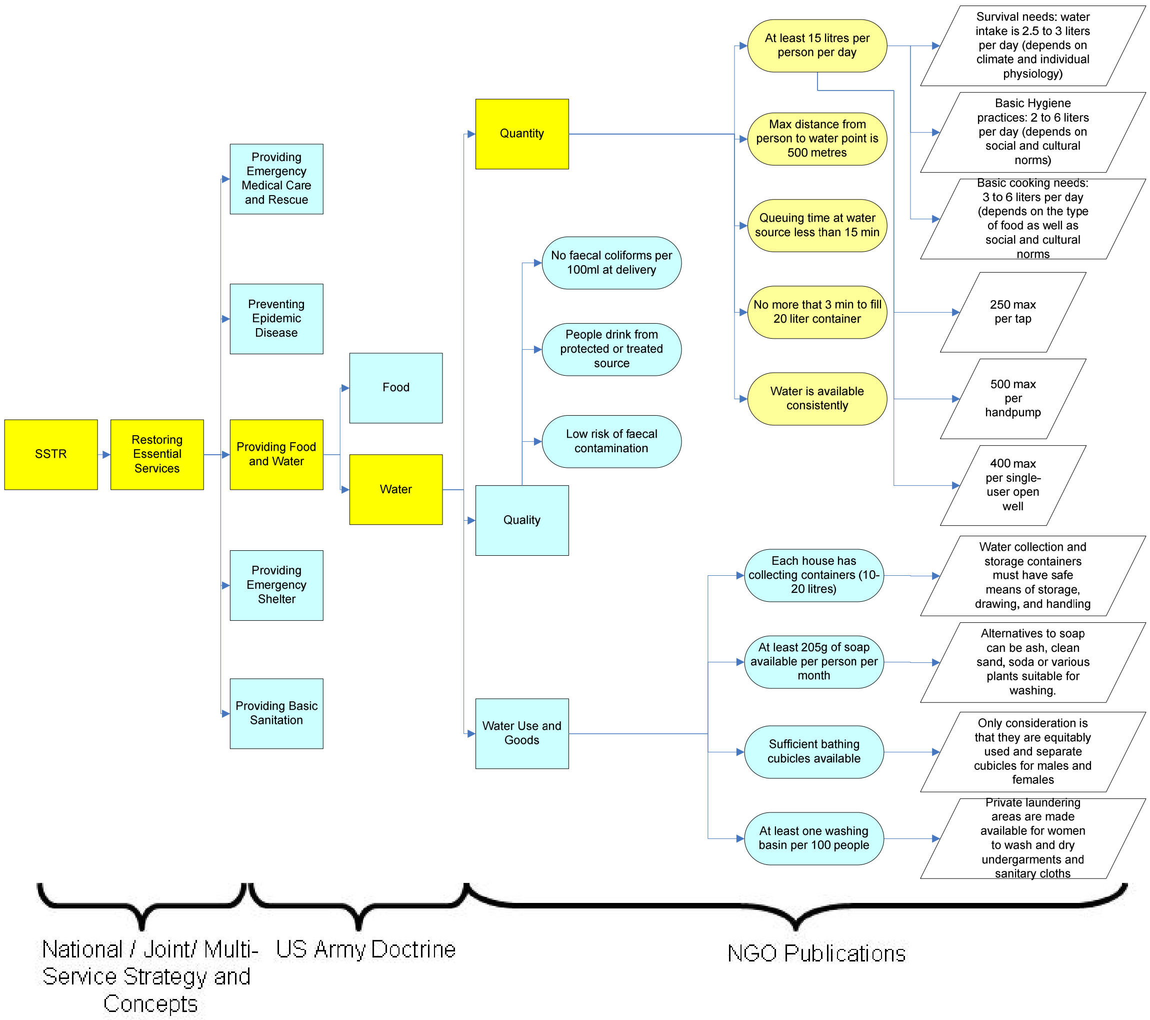

Figure 9. Complete Process From Policy to MOEs – Water

E. STATE VARIABLES AND DATA ELEMENTS REQUIRED

By using Army Doctrine and NGO publications on water standards as the basis for a proof of concept one can derive a more accurate simulation to

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129 The Sphere Project (2004), Humanitarian Charter and Minimum Standards in Disaster Response, Geneva:Steering Committee for Humanitarian Response, p. 63.

quantify variables. The tangible elements of providing water can be quantified. Specifically, the amount of water available on a daily basis translates to requiring a dynamic simulation of time passing and the amount of water each person has access to everyday. Since the maximum distance is a key indicator, the environment must have a geospatial representation, in which a person has a position, and the distribution center of the water has a position. In addition, giving positions to the production and storage facilities will allow federation of simulations that includes a military kinetic simulation to do tasks akin to physically disrupting or enhancing key components of the infrastructure.

Next, the process of getting the water from source to destination should be analyzed. In particular, to measure queuing time, the process of receiving water must be expanded. An example is a simple server model in which the serving process is broken into the discrete events: arrival, start service, and end service.[130] (See Figure 10). The advantage of using this model is that statistical analysis can readily be done regarding queuing time, server utilization, and total time in service. These statistics directly answer the queuing time and can answer the service time metric with simple adaptation.[131] Furthermore, this model is highly "componentized". It allows for removal or replacement of each model with a more complex model, if required. Finally, the military decision maker will need to precisely define the remaining metric of consistent water access. In general, if the definition can be captured in an extension of the simple server model, then the framework will require little adaptation.

[130] Arnold Buss, (2002), Proceedings of the 2002 Winter Simulation Conference: *Component Based Simulation Modeling with SimKit*, San Diego, CA: ACM, p. 244.

[131] For clarification, service time *equals* total time *minus* queuing time.

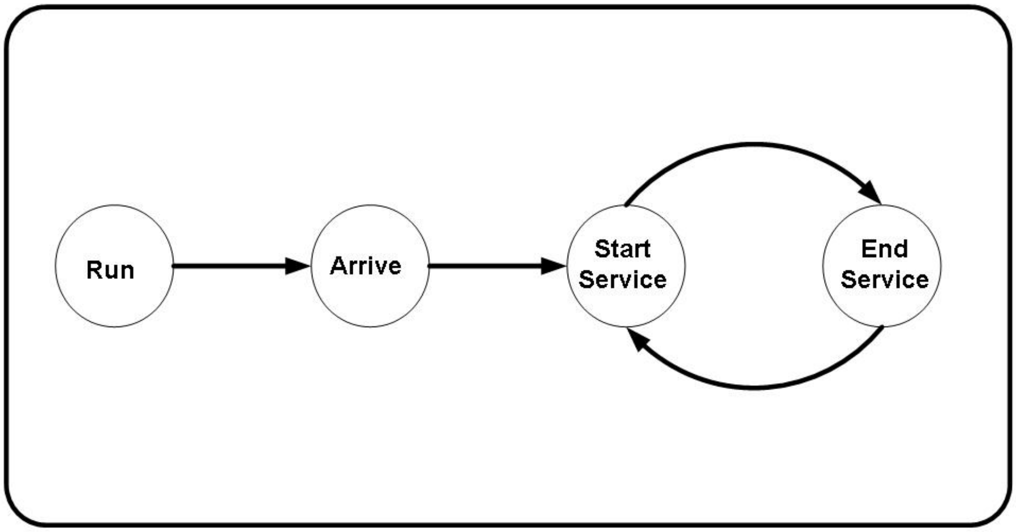

Figure 10. Simple Server Model

F. METRICS

1. MOPs—Necessary and Sufficient for Simulating Water Standard 1 (These are Items that the Military Decision Maker Can Control to Measure Effects)

- Production Amount -- Amount of water produced by a specific production facility every production cycle
- Production Service Time -- Amount of time a production facility takes to produce water in one production cycle
- Storage Capacity -- Amount of water that can be stored after being produced and before beginning to be transported to the distribution facility
- Transportation Amount -- Amount of water transported by a specific transportation method during each mission
- Transportation Service Time -- Amount of time a each mission takes to transport water from the storage unit to the distribution facility
- Distribution Amount -- Amount of water distributed by a specific distribution facility every distribution cycle
- Distribution Service Time -- Amount of time a distribution facility takes to distribute water in one distribution cycle
- Location of the non-indigenous owned distribution process -- geographical location of temporary distribution facilities. These

can be NGO, U.S. military, or other relief organization operated distribution sites. This MOP is useful when measured against population locations.

- Location of a newly constructed element of the water infrastructure -- geographical location of a permanent addition to the water supply system. Typically this facility will have an owner and will be part of an overall Produce-Store-Transport-Distribute process.
- Time to complete building a new element of the water infrastructure -- measure the time from beginning the construction until the facility is operational and provides any non-zero improvement to the water system.

2. MOEs—Necessary and Sufficient for Simulating Water Standard 1

- Number of times a person does not receive a specified amount of water per time cycle (15 litres/day)
- Number of people that went without water because of the distance requirement
- Average Queuing Time for each Distribution Process (can be expanded to analyze the distribution of the queuing time)
- Average Service Time for each Distribution Process given a specified distribution amount requirement (20 litre per cycle) (can be expanded to analyze the distribution of the service time--but this is probably a parameter)
- Other MOEs can be derived from mathematical combinations of the MOPs and MOEs such as % of total population that is provided water

G. SUMMARY

Model, architecture, and measurements requirements are now defined. Numerous methodologies can be applied to design the model to meet the requirements, but one approach of particular interest is agent-based modeling. This modeling technique is finding widespread application for biological, social and cultural modeling, as well as for military simulation and analysis. The next chapter provides a brief overview of agent based modeling, with particular focus on a modeling framework for multi-agent systems.

V. AGENT BASED SYSTEMS

So when a falling grain hits there's no telling what might happen. Maybe nothing. Maybe just a tiny shift in a few grains. Or maybe, if one tiny collision leads to another in just the right chain reaction, a catastrophic landslide will take off the whole face of the sandpile.

-- M. Mitchell Waldrop[132]

A. INTRODUCTION

Agent Based Models (ABMs) are computational models that simulate the actions and interactions of small solvable problem sets that lead toward emergent behavior. This chapter provides a brief overview of this modeling technique, laying out a framework for the conceptual design for the proposed model of restoration of essential services.

B. AGENT BASED MODELS AND MULTI-AGENT SYSTEMS

Agent Based Models (ABMs) are computational models that simulate the actions and interactions of small solvable problem sets that lead toward emergent behavior. The Military Operations Research Society (MORS)[133] describes ABM at the 2005 MORS Workshop in the following way:

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[132] Mitchell M.Waldrop (1992), *Complexity: The Emerging Science at the Edge of Order and Chaos*, New York: Simon and Schuster, p. 49-50.

[133] The Military Operations Research Society (MORS) is a society for professionals active within defense applications of operations research (OR) in the United States. MORS operates under the sponsorship of the Army, Navy, Air Force, Marine Corps, Office of the Secretary of Defense, the Joint Staff and the Under Secretary for Science and Technology, Department of Homeland Security. Its objective is to enhance the quality and effectiveness of military operations research though symposia and courses, published books, a quarterly bulletin called *Phalanx*, and a peer review journal called *Military Operations Research*. Further information on MORS can be found at http://www.mors.org/ Accessed on 12 August 2008.

Agent Definition[134]

- An autonomous software object that makes decisions and takes action based on its perceptions about its environment.

Agent Characteristics[135]

- Software object
- Embedded in a simulated world
- Individual world view/model (sense, perceive, think, decide, act)
- Autonomous (no external or centralized control)
- Set of interfaces with its environment and other agents

Agent-Based Modeling Dimensions[136]

- Autonomy
- Multiple agents
- Heterogeneity
- Complexity (Intelligence level) of agent
- Interactions with other agents
- Interactions with the environment
- Environment

Multi-Agent Systems (MAS) originated in the military with the multi-agent based land combat model called ISAAC (Irreducible Semi-Autonomous Adaptive Combat).[137] Analytical simulations still use ABM technology from ISAAC today, like Pythagoras and Map-Aware Non-uniform Automata (MANA). However, MAS is a more advanced concept than the MORS ABM because it takes a systems

134 *MORS Workshop*, p. 18.

135 Ibid., p. 18.

136 Ibid., p. 18-19.

137 ISSAC is a MAS that "takes a bottom-up, synthesis approach to the modeling of combat, vice the more traditional top-down, or reductionist approach, and represents a first step toward developing a complex systems theoretic analyst's toolbox for identifying, exploring, and possibly exploiting emergent collection patterns of behavior on the battlefield." Andy Ilachinski (2000), Irreducible Semi-Autonomous Adaptive Combat (ISAAC): An Artificial-Life Approach to Land Combat. Military Operations Research, volume 5 (issue number 3), p. 29.

engineering approach that includes additional critical facets. Jacques Ferber's MAS model best describes these facets, by defining an agent as:

- Capable of acting in an environment
- Communicates directly with other agents
- Driven by a set of tendencies
- Possesses resources
- Capable of perceiving its environment
- Has only a partial representation of this environment
- Possesses skills and can offer services
- May be able to reproduce itself
- Behavior tends towards satisfying its objectives, taking account of the resources and skills available to it and depending on its perception, its representations and the communications it receives[138]

Agents capable of autonomy are not controlled by the user's commands, but are directed by programmed internal tendencies.[139] Goals, satisfaction algorithms, or other optimization methods are different ways to implement these tendencies. This thesis combines the MORS and Ferber's MAS definitions of "Agent" to encompass a more robust and capable agent.

As powerful as MAS is, there are limitations. The nature of micro parameters to macro variable relationships leaves an unclear traceability to explain outcomes. "Sealed-off [describes how it is] not possible to make the behaviors executed at the micro level correspond with the global variables measured at the macro level."[140] In addition, social data inputs have lower than traditionally accepted R^2 values by analysts. This limits the utility of MAS in

[138] Jacques Ferber (1999), *Multi-Agent Systems: An Introduction to Distributed Artificial Intelligence*, London: Addison-Wesley, p. 9.

[139] Ibid.

[140] *Multi-Agent Systems: An Introduction to Distributed Artificial Intelligence*, p. 35.

modeling SSTR Operations to gaining insight, and not to be a predictor. Furthermore, the simulation outcomes will be a probability distribution.[141] Another limitation is based on the complexity and realism of the input parameters.[142] Much of the time, the parameters that drive a MAS are difficult to estimate or collect. While this can be a significant limitation or even prevent the simulation from having any usefulness if the data are unavailable, the four previously defined input data collection methods can mitigate its negative impact. Despite these limitations, MAS provides the military decision maker a miniature virtual laboratory to explore possibilities or to reveal to military decision makers an environment that was previously unavailable.[143]

Inherent to computers is the need to quantify all information, but the social domain's critical information is qualitative. This qualitative information is difficult to capture, but in order to use a computer simulation, the numeric representation of qualitative variables must be defined.[144] An example of how to overcome this dilemma comes from the Pythagoras Counterinsurgency (COIN) Application to Support the Marine Corps Irregular Warfare (IW) Study.[145] The concept being modeled was the qualitative relationship of whether individual factions support the established government or the insurgents. The authors chose a series of discrete states as the model.[146] This was a simplification but it still provided utility to the analysts. Estimation of persuasion was also modeled to some degree.[147] Social SMEs tend to resist attributing quantitative measures to qualitative information; however, doing so allows a military decision maker to begin simulating previously unavailable environments.

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[141] MORS Workshop, p. 13.

[142] Ferber, p. 35.

[143] Ibid., p. 37.

[144] Ibid., p. 35.

[145] Northrop Grumman Mission Systems. (2007). *The Pythagoras Counterinsurgency (COIN) Application to Support the marine Corps Irregular Warfare (IW) Study*. (Interim Report Number 2). Fairfax, VA: Mitch Youngs and Edmund Bitinas.

[146] Ibid., p. 3-3.

[147] Ibid., p. 3-8.

C. ELEMENTS OF MAS

The Agent, however, is merely one part of the overall system. To maximize the utility of the agent, the rest of the system needs to be defined. The MAS design encompasses five key elements: Environment, Agent, Operations, Objects, and Laws.[148]

1. Environment

MAS have boundaries that define the simulation's domain and its usefulness; which are captured in an environment model. The environment is typically a space that has volume, and it conceptually articulates the context in which the agents interact. For example, in many kinetic warfare simulations, the agents shoot, move, and communicate in a two or three-dimensional grid. However, in modeling social network behaviors, physical location may have little meaning, and the environment can be a simple series of arc-nodes representing the social networks in which agents operate within it. In Task Network Model simulations, the process itself becomes the environment that defines the boundaries for agents exploring the process. Overall, the problem domain provides guidance to describe the environment.

2. Agent

The agent's internal concepts consist of three generic divisions, an input suite, output suite, and a representation of the agent's world. In order to ensure simplicity and a bottom up approach to solving a problem, agents have a limited scope of decision capability that is based on well-understood basic decisions and representations.[149] The input suite defines how the agent will receive and perceive its environment. A well-defined input suite allows for errors in ground truth, such as individual perceptions, bias implementations, incorrect information, and other factors that the agent uses to perceive its environment. The designer

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[148] Ferber, p. 11-12.

[149] Ibid., p. 11.

can implement features deemed important to an analyst or trainer. The output suite defines how the agent will interact with its environment. However, the crux of the agent is in how the representation of the agent's environment is designed. In a famous example of a simple Ferber based MAS—the El Farol Bar problem[150]—the representation was a simple numeric estimation. The complexity of the agent's representation is only limited by the designer's imagination. For the agent a critical aspect is the need for loosely coupled design architectures. The internal representation must be able to remove, add, or extend different components to meet flexibility requirements. Finally, the representation must encapsulate how the agent makes a decision among the programmed choices and evaluate the "what ifs" that are relevant to the designer.

3. Operations

Operations are the set of agent actions that make up the output suite. The operation design governs how the agent acts within the environment, as it interacts with other agents and objects. An important criterion is to only design and model operations that are relevant to the multi-agent simulation. In addition, each agent does not require access to all the operations. Some creative designs can have a dynamically assigned set of operations as a subset of the agent population.

4. Objects

Objects are design features that do not make a decision but can be "sensed" or "manipulated" by agents. Typical ways agents manipulate objects is

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[150] The El Farol bar problem, created by W. Brian Arthur, is a problem in game theory. It is based on a bar in Santa Fe, New Mexico. Frequently, this problem is simulated as an introduction to MAS. The scenario is that agents decide every Thursday night, to go to the El Farol Bar or stay at home. The agent makes this decision based on the anticipated attendance, which is represented by a numerical value in its internal representation of the environment. W. Brian Arthur (1994). Inductive Reasoning and Bounded Rationality (The El Farol Problem). The American Economic Review, volume 84 (issue 406), March, 30, 2007. Accessed 4 August 2008, from http://www.santafe.edu/~wbarthur/Papers/Pdf_files/El_Farol.pdf.

to create, destroy, or modify.[151] The original Ferber model categorizes the relationships between agents and objects as an independent element of the MAS. For simulations that allow agents to perceive, create, destroy, or modify relationships, then the relationship element is a subset of the object design. Objects need to have a position in the MAS environment, whether that is a location on a spatial grid or a "node position" in a social network. Where an object is located is dependent on how the environment is modeled. Lastly, objects that are specified should have relevance to the designer and affect how the agent acts or makes decisions.

5. Laws

The Laws define the "how" of the MAS. Laws govern the application of the agents' operations and how the environment reacts to each operation.[152] For physical simulations, the laws can be based on physical sciences, such as motion. However, for simulations influenced by the social sciences, the laws may be open to debate. As an example, U.S. Army Training and Doctrine Command (TRADOC) Analysis Center (TRAC)[153] has modeled how agents change positions on issues using a Bayesian Belief Network (BBN). During a recent Human Simulation of Culture and Behavior, some of the social science SMEs proposed alternate theories to using BBN. For this reason designers should take care to ensure the "how" retains its component design, in order to allow the analyst or trainer to utilize different theories.

D. SUMMARY

MAS is a promising technique for addressing the set of requirements identified in Chapters III and IV. The self-adaptive nature of some of these

[151] Ferber, p. 11.

[152] Ibid.

[153] The principal research activity for the U.S. Army Training and Doctrine Command (TRADOC) Analysis Center (TRAC) is TRAC-Monterey, located at the Naval Postgraduate School.

models may facilitate broad exploration of battlefield scenarios and permit the possibility of gaining substantial insights into both military and non-military emergent behaviors. This may be especially pertinent for a non-linear battlefield with distributed tactical units.[154] However, before proceeding with new model design and implementation, the state of the art needs to be evaluated to determine if existing models can meet the stated requirements. The next chapter provides this assessment.

[154] MORS Workshop, p. 8.

VI. SURVEY OF CURRENT SIMULATIONS

The modeling of cognition and action by individuals and groups is quite possibly the most difficult task humans have yet undertaken. Developments in this area are still in their infancy. Yet important progress has been and will continue to be made. Human behavior representation is critical for the military services as they expand their reliance on the outputs from models and simulations for their activities in management, decision making, and training.

-- National Research Council (1998)

A. INTRODUCTION

The next step is to evaluate the simulations that are in use or actively being developed against the established requirements previously discussed. Over the past several decades, military simulations have largely focused on kinetic warfare. Therefore, simulations that have been not been in active development since the creation of SSTR doctrine are assumed unable to support restoration of essential service requirements. The remaining simulations must support all requirements and produce anticipated MOEs. It is not possible to do a complete review of all existing and under-development simulations in this thesis. However, a representative sample has been selected based on their established reputation within DoD or by virtue of their current funding levels:

1. Analysis

- Combined Arms Analysis Tool for the 21st Century (COMBAT XXI)
- Pythagoras
- Naval Simulation System (NSS)
- Simulation Testing Operations Rehearsal Model (STORM)

2. Training

- Marine Air Ground Task Force (MAGTF) Tactical Warfare Simulation (MTWS)
- Joint Conflict and Tactical Simulation (JCATS)
- One Semi-Automated Forces (OneSAF)

3. Commercial and International

- Map-Aware Non-uniform Automata (MANA)
- Synthetic Environments for Analysis and Simulation (SEAS)
- Performance Moderator Function Server (PMFserv)
- Peace Support Operations Model, Version 2 (PSOM2)

For clarity and conciseness, only limitations in the simulation, which will include ambiguous capabilities, are addressed.

B. ANALYSIS

1. COMBAT XXI

COMBAT XXI is a high-resolution, closed-form, stochastic, analytical combat simulation still in development at the TRADOC Analysis Center – White Sands Missile Range (TRAC-WSMR). COMBAT XXI is a replacement for Combined Arms and Task Force Evaluation Model (CASTFOREM) and will be used for the analysis of the joint battlespace in the Research, Development and Acquisition, Advanced Concepts and Requirements, Modeling and Simulation domains. TRAC-WSMR is working in a partnership with the Marine Corps Combat Development Command (MCCDC).[155]

[155] Sergio Posadas (2001), *Stocastic Simulation of a Commander's Decision Cycle (SSIM CODE)*, Master's Thesis, Naval Postgraduate School, Monterey, CA, June 2001, p. 3.

COMBAT XXI encompasses all kinetic elements of ground warfare, aviation operations and amphibious operations. This simulation will "provide details of how combat outcomes are dependent on understanding the way quality of military decision-making is conditioned by information flow on the battlefield."[156] It will also advance the understanding of Information Operations and Information Warfare. COMBAT XXI is intended to support force-on-force analysis, specifically weapons system development, and test and evaluation. It will also support analytical needs like force design, operational requirements, mission area analysis and warfighting experiments.[157]

COMBAT XXI will support analysis for modeling activity for all services once complete. However, this simulation will be limited to kinetic warfare and cannot simulate a humanitarian crisis, like the restoration of an essential service, specifically water. Since it cannot simulate humanitarian crisis, it will not be able to meet another requirement of accepting or be evaluated against International Standards for water disaster relief. Lastly, it currently has not published or disseminated event graphs that explain the software architecture. This hinders collaboration with other organizations and impedes the verification that the architecture is loosely coupled.

2. Pythagoras

Pythagoras is an agent-based, time-stepped model, developed by Northrop Grumman. Pythagoras users create autonomous, tendency-based agents that make decisions from multiple primitive rules. During scenario runs, analysts can observe emergent behavior, as well as gather statistical data after the completion of the simulation. Pythagoras is mainly a combat model; it can represent military actions of various kinds of operations, including aspects of a

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[156] Department of the Army (1990), *Descriptive Summaries of the Research, Development, Test and Evaluation: Supporting Data FY 2009 Budget Estimate*, (Army Appropriation, Budget Activities 6 and 7, Volume III), Accessed 4 September 2008, from http://www.someaddress.com/full/url/http://www.asafm.army.mil/budget/fybm/FY09/rforms/vol3.pdf, p. 41.

[157] Ibid.

stabilization operation. This includes patrolling areas, hunting down terrorists, responding to terrorist attacks, and civic affairs operations (like actions affecting mass media or taxes that influence the public).[158]

The current version of Pythagoras does not allow for a proper social network representation.

> Due to the necessary reset of attitudes after a color change, the information transferred through the social network is inaccurate. The limitations of the current software make it impossible to realize an accurate social network representation and therefore some more code changes are needed to represent and analyze the interactions of a populace.[159]

There is a capability in Pythagoras to model the production and supply of resources needed for essential services. However, it is hard to model important aspects of a stabilization operation and human behavior that are needed to monitor success in restoration of essential service. Furthermore, Pythagoras does not have the capability to accept social relationship models as critical inputs or be wrapped to provide data to social model add-ons. If there are competing social theories, Pythagoras does not allow for both to be tested. Parameters that guide the measures of success for Pythagoras do not include principals from national and international disaster response agencies. Lastly, since Pythagoras is a tightly coupled design, any modifications require detailed software revisions that can hinder collaboration with other organizations.

3. NSS

NSS is a closed form, high resolution, discrete event, Monte Carlo simulation developed by Metron, with related efforts by Lockheed Martin, Northrop-Grumman, Boeing, Space and Naval Warfare System Command (SPAWAR). NSS is used for Campaign Analysis, Naval Forces Studies, and

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[158] Thorsten Seitz (2008), Representing Urban Cultural Geography in Stabilization Operations: Analysis of a Social Network Representation in Pythagoras, Master’s Thesis, Naval Postgraduate School, Monterey, CA, June 2008, p. 11, 71.

[159] Ibid. p. 71.

Course of Action Analysis. The database that comes with the NSS contains a large volume of data from agencies such as the Defense Intelligence Agency (DIA), the Office of Naval Intelligence (ONI), the Naval Warfare Development Center (NWDC), SPAWAR, and other naval national commands. NSS can model naval platforms and facilities while testing the commander's plans and doctrine. NSS can provide analysis for Information collection, Information dissemination, fusion, dynamic planning and re-planning, war fighting interactions, detection, and logistics.[160] It is a very effective tool for kinetic simulation, allowing users to create a combat scenario.

Like COMBAT XXI, NSS is limited to kinetic warfare and cannot simulate a humanitarian crisis. It also will not meet International Standards for water disaster relief. Lastly, NSS is a commercial, off-the-shelf (COTS) simulation and any modification will have to be vetted through the contractors. Even if the simulation was modified to support the first requirement of averting humanitarian crisis, the next requirement would require social relationship models need to be coded into the simulation, making it very expensive. This would marry all software improvement to a specific architecture, also hindering collaboration with other organizations.

4. STORM

STORM is a man-in-the-loop, real time, stochastic simulation and is intended to be federated with other High Level Architecture (HLA) complaint simulations, such as JCATS. US Army Operational Test Command in Fort Hood (USAOTC) led the development of STORM. Electronic Proving Ground (EPG) in Fort Huachuca and Fort Lewis, TRAC-WSMR, and the Communications-Electronics Research Development and Engineering Center in Fort Monmouth (CERDEC) developed the federated components. Primary function of STORM is

[160] Metron (1999), *Use of Modeling and Simulation (M&S) in Support of Joint Command and Control Experimentation: Naval Simulation System (NSS) Support to Fleet Battle Experiments*, Solana Beach, CA: Colleen M. Gagon and William K. Stevens, Retrieved 4 September 2008, from http://www.dodccrp.org/events/1999_CCRTS/pdf_files/track_2/004steve.pdf.

to load live tactical *Force XXI Battle Command, Brigade-and-Below* (FBCB2) systems with message traffic reflecting state of federated simulation.[161] The task of FBCB2 is to provide situational awareness, and command and control to the lowest tactical echelons. This is intended to facilitate the flow of battle command information across the battlespace.[162] STORM is also designed to increase the realism of live simulation by augmenting the accuracy of tactical communications between Tactical Operations Centers (TOC), platforms, and soldiers.[163]

STORM has a force-on-force, target-attrition emphasis. Although STORM supports and analyzes higher level objectives such as establishing air supremacy, defeating warfighting forces, or disrupting enemy leadership, "[it is] not adequate to satisfy EBO wargaming requirements."[164] Currently, the DoN has partnered with Department of the Air Force for a planned STORM 2.0 version that is sometimes referred to as "STORM+". This update is postured as an open-system architecture, open-source approach, modular implementation, object-oriented design that will support naval core missions, such as Anti-Submarine Warfare, Anti-Surface Warfare, Coastal Maritime Irregular Warfare, and Expeditionary Warfare. The full details of what STORM+ will support are still under development. Nonetheless, there are no known documented requirements for it to simulate operations that support reconstruction operations that avert humanitarian crises.

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[161] Simulation Interoperability Standards Organization, *Simulation, Testing, Operations, Rehearsal Model (STORM) A Testing and Training Tool for Lower Echelon Command and Control Systems*, Tacoma, WA: Thomas Christopherson, Accessed 5 September 2008 from http://www.sisostds.org/index.php.

[162] Shane Robb (April-June 2007), Force XXI Battle Command Brigade and Below (FBCB2) Past, Present and Future, *Army AL&T*. Retrieved 5 September 2008 from http://asc.army.mil/docs/pubs/alt/2007/2_AprMayJun/articles/80_Force_XXI_Battle_Command_Brigade_and_Below_(FBCB2)_Past,_Present_and_Future_200704.pdf. Definition, capabilities, limitations, and family of system is further described in the article.

[163] Christopherson, *STORM A Testing and Training Tool.*

[164] Maris McCrabb and Joseph Caroli, *Behavioral Modeling and Wargaming for Effects-Based Operations*, Accessed 4 September 2008, from http://www.mors.org/meetings/ebo/ebo_reads/McCrabb_Caroli.pdf. EBO stand for Effects Based Operations, which has been replaced by Interconnected Operational Environment in JP 3-0.

C. TRAINING

1. MTWS

Designed to support training of U.S. Marine Corps commanders and their staffs, MTWS is a computer-assisted warfare gaming system that provides a full spectrum of combat models required to support U.S. Marine Corps exercises. MTWS is an aggregate level, continuous, stochastic, human in the loop simulation contractually supported by L3 Communications and Titan.

> The major functional areas [in MTWS] are Ground Combat, Air Operations, Fire Support, Ship-to-Shore, Combat Service Support, Combat Engineering, and Intelligence. The system provides limited play in Electronic Warfare, Communications, and Nuclear, Biological, and Chemical Warfare.[165]

Another function of MTWS is for the planning of tactical operations and evaluating that same plan with an alternative enemy or environmental conditions.

MTWS enables the user to have engineering capability within a scenario. However, this capability is limited to clearing minefields, removing obstacles and barriers, and building structures, obstacles, barriers, minefield, roads, and bridges. It does not include any capability that is needed for restoration of essential services, like any of the DoN capabilities needed to model – creation, transportation, and distribution – for water.[166]

MTWS is limited to kinetic warfare and the instructors script any humanitarian crisis scenario. This means that there is no critical input of a social relationship model as well. Currently, the MAGTF has added that they want capability to "provide interagency support by specifically obtaining midgrade interagency and non-government organization (NGO) SME/LNO planning and

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[165] Curtis Blais, (1994), Proceedings of the 1994 Winter Simulation Conference: *Marine Air Ground Task Force (MAGTF) Tactical Warfare Simulation (MTWS)*, San Diego, CA: ACM, p. 839.

[166] Ibid. p. 843.

integration expertise."[167] This echoes the requirement of having the simulations include parameters that would guide the measures of success by including principals from national and international disaster response agencies. Furthermore, the users have begun the formal process to increase the simulation's capability specifically in this domain:

> The infrastructure of the host or assisted nation needs to be represented within the simulation model so the actions on the infrastructure affect the civilian population groups thus creating higher order effects throughout the simulation. Examples of infrastructure modeling:
>
> - Water and sewage treatment
> - Water distribution
> - Fuel distribution
> - Infrastructure maintenance and construction[168]

In addition, modifications to MTWS are difficult, and the data are not easily accessible, since 95 percent of the software code is written in Ada under a software design dating to the early 1990's. Moreover, funding for the program is limited and uncertain beyond fiscal year 2009.

2. JCATS

JCATS is a high resolution, event-stepped, entity level model that can be federated with other simulations. JCATS has the flexibility to simulate a wide range of conflicts and scenarios, from conventional combat to security operations. Developed by Lawrence Livermore Laboratory and administered by Joint Forces Command, JCATS utilizes probabilities of hit and probabilities of kill to determine outcomes between entities. JCATS' developers describe the model

[167] MAGTF TC (2007), Issue Ranking Report by Program w/ Recommended OPR for OM Review, Retrieved 20 August 2008, from http://www.dtic.mil/doctrine/training/wjtsc07_2wg_jntcompatmagtftc.pdf.

[168] This is from a draft Universal Needs Statement from the director of the MAGTF Staff Training Program, who manages use of MTWS for USMC staff training. (Johnnie Frame, personal communication, 7 October 2007).

in general terms as a “computerized sand table.”[169] Decision makers can use the model for rehearsing missions, exploring security scenarios, or exercising tactics, techniques and procedures.[170]

This simulation can provide highly accurate representations of kinetic military in the real world. JCATS can simulate up to 60,000 different elements. JCATS models complex environments, such as like urban areas, providing high fidelity for realistic scenarios. It can model scenarios like drug interdiction, disaster relief, and hostage rescue.[171]

However, JCATS is limited to security and combat operations. Although the software claims to simulate disaster relief, it does not have capability to simulate producing, storing, transporting, and distributing essential services. Furthermore, it does not measure or evaluate against International Standards nor does it interface with social models that measure the reaction of the population to the support provided. Even though JCATS is administered by Joint Forces Command, the software’s design is managed by Lawrence Livermore and is not loosely coupled enough to allow for social model add-ons. Any such add-ons would have to be integrated into the core software. Furthermore, any unit that wants to collaborate with another that is using JCATS must use JCATS, create a new federation, or attempt to adapt an existing federation. As more simulations are federated together, the federation gains capabilities of the individual components. To date, the federations are limited to kinetic warfare simulations that cover specific military domains and do not include restoration of essential service requirements. However, this federated approach is a good way forward to integrating this design into non-SimKit kinetic warfare simulations.

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169 Kenyon Henry S. (October 2002). "Modeling to Thwart Terrorism." *SIGNAL Magazine*. Retrieved 5 September 2008, from https://www.afcea.org/signal/articles/templates/SIGNAL_Article_Template.asp?articleid=327&zoneid=97.

170 "Modeling to Thwart Terrorism."

171 Arnie Heller (February 2000). "Simulating Warfare is No Video Game." *Science and Technology Review*. Retrieved 5 September 2008, from https://www.llnl.gov/str/pdfs/01_00.1.pdf.

3. OneSAF

OneSAF Objective System (OOS) is the Army's next generation, entity based, entity level, simulation system that represents combined arms tactical operations up to the battalion level. It can provide both, command level human in the loop training and closed-form analytical support. Developed by US Army, Program Executive Office-Simulation Training and Instrumentation (PEO-STRI), OOS is an open architecture, open-source software, loosely coupled, and modular design.[172]

The purpose of the simulation is to experiment with new concepts and advanced technologies to develop requirements in doctrine, training, leader development. OOS includes most forms of training at echelons from the individual soldier through collective, combined arms, joint and/or combined exercises, allowing for mission rehearsals and evaluations of all phases of war plans. OOS also acts as a virtual environment with the purpose of discovering or revising facts and theories of phenomena occurring in the battlefield. OOS is a tool for rehearsal, evaluation or validation of a combat plan.[173]

This simulation is highly flexible and is responsive to requested military changes. However, OOS is limited to kinetic warfare and cannot simulate any process in averting humanitarian crisis. As such, it cannot be used as a tool to measure International Standards for disaster relief either. If a social model of a civilian was created, then the system will need to be adapted to handle these events.

[172] Mr. Doug Parsons and LTC John Surdu, *The U.S. Army's Next Generation Simulation Modelling the Response to the World's Future Threat*, Accessed 5 September 2008, from http://www.onesaf.net/community/index.php?option=com_wrapper&Itemid=54.

[173] MITRE Coorporation. (February 2001). *OneSAF: A Product Line Approach to Simulation Development*. Orlando, FL: Robert Whittman. Accessed 5 September 2008 from http://www.mitre.org/work/tech_papers/tech_papers_01/wittman_one_saf/index.html.

D. COMMERCIAL AND INTERNATIONAL

1. MANA

MANA is a closed form, stochastic, agent based, low resolution simulation developed by New Zealand's Defence Technology Agency for use as a scenario-exploring model to address a broad range of problems. The intent was for it to enable analysis of the value of factors like situational awareness, command and control, and information warfare. Its environmental domains include land and sea surface. MANA is based on the two key ideas:

- The behavior of entities within a combat model (both friend and foe) is a critical component of the analysis of the possible outcomes.
- We are wasting our time with highly detailed models for determining force mixes and combat effectiveness.[174]

The objective of MANA is simplicity. The model has five sets of parameters: general battle settings, personality parameters, ranges and constraints, terrain data and weapon data. The parameters provide battlefield and personality information, like starting location and aggression level toward the enemy.[175] All parameters are simplified to a single decimal value that is typically used as a weighting multiplicative factor. The sum of these factors determines the agent's actions.

MANA is strictly for modeling kinetic combat. MANA is not "suitable for modeling peace support operations…[For effects on population analysis, there is a] need to introduce civilians into the model and define them differently to military agents."[176] Furthermore, MANA is managed by an international agency that maintains control over its future development. The designers and the developers

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[174] Arif Ilker Ipekci (2002), How Agent Based Models Can Be Untilized to Explore and Exploit Non-Linearity and Intangibles Inherent in Guerri, Master's Thesis, Naval Postgraduate School, Monterey, CA, June 2002, p. 24.

[175] M. R. Bathe and L.Frewer, (2005), The Cornwallis Group IX: Analysis for Stabilization and Counter-Terrorist Operations: *Modelling Peace Support Operations: An Agent-Based Approach*, Clementsport: Cornwallis Group, p. 98.

[176] Ibid., p. 104.

restrict MANA's capabilities in order to maintain niche specialization; therefore, it is not suitable for meeting any of the essential service requirements outside of being a kinetic simulation.

2. SEAS

SEAS has been boasted as the solution for many DoD simulation needs, including simulating humanitarian crises. According to Joint Forces Command, SEAS is evaluated as a simulation that has "the non-kinetic aspects of combat, things like the diplomatic, economic, political, infrastructure and social issues."[177] This Simulex product, developed at Purdue University, is an agent based, high resolution simulation has models for different geographical location. Models for Iraq and Afghanistan, each that have up to five million individual nodes representing things such as hospitals, mosques, pipelines, and people.[178]

Due to the proprietary nature of SEAS, the software source code is a "black box." The military decision maker cannot evaluate the root causes and effects in the simulation nor can the final assessment be traced to causal factors. Furthermore, the conceptual model cannot be verified and is ambiguous, so it is impossible to determine whether the simulation meets the five requirements for supporting naval operations for the restoration of essential. Most proprietary models have the same problems as SEAS. Many claim to be the solution, but without the ability to have a complete verification process—both of the conceptual model and the implementation—these simulations will not meet simulating essential service requirements.

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[177] U.S. Joint Forces Command (2004). USJFCOM Teams with Purdue University to add the Human Factor to War Game Simulations. Accessed 5 September 2008 from http://www.mgmt.purdue.edu/centers/perc/html/Media/USJFCOM.htm.

[178] Mark Brad, (23 June 2007). Sentient World: War Games on the Grandest Scale. *The Register.* Accessed 5 September 2008 from http://www.theregister.co.uk/2007/06/23/sentient_worlds/page2.html.

3. PMFserv

"PMFserv is a human behavior modeling framework that manages an agent's perceptions, stress and coping style, personality and culture, social relationships, and emotional reactions and affective reasoning about the world."[179] This agent framework centers around a simulation that tracks three categories of resources. One of the resource categories includes economic goods available to the members, which are described as jobs, money, food, training, and healthcare.[180] The claim that this framework can drive agent based entities in other simulations such as Unreal Tournament and Joint Semi-Automated Forces.[181]

Much like SEAS, PMFserv is another "black box." Further, the agents in the framework make decisions based on control of the resources and not based on humanitarian needs. Overall, this model provides a framework to test social theories but does not simulate a humanitarian crisis based on international standards.

4. PSOM

PSOM2 is a human-in-the-loop, time-stepped semi-automated facet of a war game. PSOM2 describes how human players interact, negotiate, and decide the actions for a turn, but the simulation carries them out. PSOM2 is more of an electronic game board with very special features and much of the key interaction between players goes on outside of the simulated environment.

[PSOM2] contains two major game play mechanics in the Operational Level Game (giving results of combat, reconstruction and the economy at the

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179 Silverman, B. G., Bharathy, G. K., Johns, M., et al. (2007). Socio-Cultural Games for Training and Analysis. (Department of Electrical & Systems Engineering Departmental Papers, University of Pennsylvania, 2007). Accessed 10 September 2008 from http://repository.upenn.edu/cgi/viewcontent.cgi?article=1334&context=ese_papers, p. 7.

180 Ibid., p. 3-4.

181 Ibid., p. 8.

operational/higher tactical context) and the High Level Game (giving inputs to the Operational game in the political/strategic context).

The model involves the simple representation of the Interconnected Operational Environment that includes infrastructure, population, economy, military (including combat), reconstruction units, and all actors in the campaign. The aim of the system is to collect MOEs of how the players provide for the simulated populace within the scenario. These effects calculated from the Operational and High Level games individually. In addition, each turn's MOEs are provided throughout the game to the players and these MOEs drive how the simulated populace supports each player's faction.

PSOM2 immerses the decision maker to some of the characteristics of the Operational Variables that make up the Interconnected Operation Environment. This allows the player to think about and understand 2nd and 3rd order effects of their decisions. However, understanding the impact of restoration of essential services requires simulated elements to go beyond the coarse level. In addition, this war-game's rules and parameters do not undergo a vetting process that is based in international standards, but based on the scenario designer's interpretation. Also, the fidelity of the kinetic aspect of the simulation is ambiguous, specifically in the military to infrastructure Operational Variable interaction. The variables may be represented, but these variables may not be connected. Moreover, much of the social interaction between factions happens outside of the simulation. The war-game requires role players to play all sides—protagonists, neutrals, and antagonists. This brings individual bias into the simulation, creating a false environment.

E. SUMMARY

The overall assessment of capabilities of these simulations to support restoration of essential service requirements is that existing simulations cannot meet all the requirements. In their respective domains, these simulations perform very well for their intended purposes. Moreover, each simulation has been designed to fulfill a specific niche role, but none have adequately branched into simulating military and non-military aspects of operations to restore essential services. Even though there are many possibilities of simulations, at the time of this writing, the simulations chosen are ones that key military analysis or training organizations are actively developing or evaluating. Since no existing simulation can satisfy the requirements, a new conceptual model must be designed.

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VII. CONCEPTUAL MODEL OF A DISCRETE EVENT SIMULATION MULTI-AGENT SYSTEM

Now the general who wins a battle makes many calculations in his temple ere the battle is fought. The general who loses a battle makes but few calculations beforehand. Thus do many calculations lead to victory, and few calculations to defeat, how much more no calculation at all!

-- Sun Tzu

A. INTRODUCTION

The conceptual model translates requirements and metrics into a simulation design. From the design, the conceptual model describes the components and is the guiding document during the implementation. This conceptual model must satisfy the stated requirements from Chapter III and be able to provide the metrics identified in Chapter IV. Using the context of chapter III, a discrete-event simulation (DES) MAS design can be created. A DES provides defined state variables, state transitions corresponding to events, and the scheduling relationships between events.[182] Furthermore, the DoN's capabilities for providing essential services are easily represented in a DES component, and effects on the population are calculable in a MAS.

B. HOW DOES A DES MAS SATISFY THE REQUIREMENTS

1. Simulating Averting a Humanitarian Crisis (AHC)

Simulating averting a humanitarian crisis can be accomplished by a DES MAS combination. Since the basic needs of individuals are well documented by international relief organizations, a MAS is a good candidate for the simulation framework. A detailed agent conceptual model can represent each of the agent's

[182] *Component Based Simulation Model with SimKit*, p. 243.

needs and regular consumption of the essential service. Agents can represent the population at various levels of aggregation (i.e., individuals, households, towns, clans, etc.). Complementing this is a DES's ability to simulate basic server components. The complete process of production, storage, transportation, and distribution (the needed resource life cycle) can be simulated in order to analyze enhancements or degradation of the individual components. In addition, since AHC mission success is time sensitive, a DES enables events to be depicted chronologically and measures time between events. This supports statistical analysis of time passage to compute quantities such as the length of time in a queue awaiting water and length of time filling water containers (two of the five international water quantity standards).

2. Accessible Data

SimKit is a DES framework for implementing and executing event graph models.[183] Utilizing SimKit's DES framework inherently provides accessible data to other SimKit components. All of the events[184] are scheduled on the event list[185] and are usable in the SimEventListener[186] pattern methodology. In this methodology, a second component can wait for a running component to execute a prescribed event. When the prescribed event occurs, it triggers the second component to begin at the desired event. Therefore, in order to satisfy the second requirement, all relevant essential service actions and interactions can be designed as events, even if no expected essential service simulation state

[183] SimEventListener is a specific software class that is foundational to the SimKit java libraries. *Component Based Simulation Model with SimKit*.

[184] Events are precisely defined concepts that occur at a specified time. When the event occurs, the simulation executes state variable changes according to design logic. In addition, if certain conditions are met, the event can schedule one or more events to occur after a specified time delay. More complex designs can even remove previously scheduled events before the event occurs.

[185] An event list is a priority queue that maintains a list of events that have been scheduled. The ordering of the queue is primarily by the simulation time the event is scheduled to execute, with a secondary ordering of a PRIORITY attribute.

[186] SimEventListener is a specific software class that is foundational to the SimKit Java libraries. *Component Based Simulation Model with SimKit*, p. 245.

variables change, since new components can connect to these events as triggers. Furthermore, each state transition is accessible under the PropertyChangeListener pattern.[187] As a result, any SimKit component that is interested in essential service simulation events and state changes has access in standard SimKit implementations.

3. Integrate with Kinetic Simulations

In order to maximize this framework's integration with next generation kinetic simulations, this design will use event-graph concepts and will be implemented in SimKit code. This enables direct integration with models like COMBAT XXI. COMBAT XXI is written in SimKit, and is intended to replace U.S. Army and U.S. Marine Corps analytical simulations.[188] In addition, SimKit is a Java based Application Programming Interface, which ensures maximum portability to computer systems. With a platform dependence restriction lifted, the analyst or instructor utilizing an existing non-SimKit simulation can implement a wrapped version of this model. Using these techniques, wrappers, such as Distributed Interactive Simulation (DIS) and HLA packet generating wrappers, enable integration with simulations that aren't necessarily written in SimKit. SimKit's accessibility provides state variable values and events to federations with these kinetic simulations enables.

4. Data Based on International Standards

Using content analysis, the Sphere Project is the most widely accepted and well defined standards for essential services.[189] Concepts and parameters used in this thesis will be derived from this document, specifically as outlined in

[187] *Component Based Simulation Model with SimKit*, p. 245.

[188] *Stochastic Simulation of a Commander's Decision Cycle (SSIM Code)*, p. 3.

[189] Sphere Project, p. 6. Over 400 organizations and 80 countries around the world contributed to the development of minimum standards that are described in the *Humanitarian Charter and Minimum Standards*; making this the widely accepted metrics in use for essential services.

Chapter IV. The parameters[190] will be implemented in such a way that allows a military decision maker to vary or alter the values for individual needs. Furthermore, if the standards are modified or others are found to be more valid, then the new standards can be used as the parameters.

5. Unclassified and Open Architecture

The classification level is set by the user of the simulation due to the nature of the data that is used as parameters or the sensitivity of the study or scenario to be executed; however, the framework source code will not contain any classified information. To increase the collaboration utility of this simulation, the framework will have an open architecture. This means that the architecture will be transparent enough for any organization to integrate this simulation with their tools/models. In today's simulation environment, theories evolve and change is a norm. Rather than creating a new simulation each time theories change, a loosely coupled design will provide maximum utility by allowing seamless replacement of full components without adversely affecting the rest of the simulation. Ultimately, the framework is the important enabling factor for this concept.

C. MAS DES CONCEPTUAL MODEL

1. Environment

The environment consists of two disjoint domains, a physical location domain and a social network domain. A geospatial grid that is overlaid with theoretical or realistic locations adequately represents the physical domain. The scale of the grid should be consistent and relevant to the operational environment and data standards. In the second domain, social networks are characterized by a composition of social ties between individual agents. For the

[190] Using a Parameter is a way to utilize the same simulation with no modification to the source code and explore different values for variables.

essential service simulation, the social ties need to describe how one agent ranks other agents in a preferential order.

2. Agents

A scale for the agent must be chosen, and it affects how an agent perceives. The agents will represent the smallest decision making unit that can affect the operational environment. The level of aggregation will determine the particulars of its input suite, internal representation, and output suite. An agent's input suite will be connected to the Laws component and will process all relevant incoming messages. However, an agent will not have access to the ground truth of the simulation, but only have access to the information that the Laws component passes to it. As capabilities are added to the simulation and more requirements are created, the input suite of the agent will need modification in order to process new input messages.

The agent's internal representation consists of state variables and decision-making processes. State variables describe an agent's current perception of reality and are inputs to decision-making processes. These processes are based on measurable water standards that guide the agent's actions and state transitions. A state variable will have a quantity, threshold, and consumption values for each essential service simulated. The quantity is the amount that the agent has access to at any point in time for consumption. A resource threshold is used to model when the agent will seek more of the resource. Furthermore, the consumption data includes the quantity and the rate of consumption that a resource is consumed for basic needs. This consumption rate is expressed as a time interval between consuming a specified quantity of the specified resource.

In the internal representation of the social environment, the agent has other state variables and decision-making processes. The state variables are lists of social ties and contracts[191] maintained by the agent. Maintaining unidirectional social ties allows asymmetrical relationships, in which the weights of the ties between agents can be different. Also, agents may not know the existence of another agent. These relationship ties will be used as a key inputs to the decision making process—how an agent will select from multiple contracts that satisfy its requirements to acquire a needed resource. Once an agent has selected a contract, the internal representation will maintain this contract for the remaining duration of the simulation, unless a need arises to reconsider contract selection.

An agent's output-suite conceptual model defines required capabilities to sense and interact with its environment. In this design, all agents will equally have access to the entire set of Operations. These Operations will be the output of agent decision-making processes and are connected to the Laws component. In addition to the explicit Operations, the SimEventListener pattern extends the output-suite to include implicitly all events inside the agent's design.

3. Operations

The two relevant Operations required for a basic essential service simulation are "finding contracts" for a specific resource and "ordering" the contract that the agent has selected. Finding contracts communicates to the Laws component that an agent needs access to a list of relevant contracts for supplying the required resource. Ordering a contract simulates an agent executing the agreed arrangement and attempting to exchange resources with the supplying agent.

4. Objects

The Objects that are relevant in the essential service system simulation primarily relate to the needed resource life cycle. In order to allow for

[191] "Contract" is a term that illustrates the connection between two nodes who exchange resources at a specified location.

enhancement or degradation of each component, a separate model object must be represented. In modeling each of these components, a server model can be used with a small extension regarding hours of operation.[192] The entire resource life cycle can be aggregated into a single object that will be assigned an owning agent. To begin with a basic building-block approach, a complete functioning essential service system will consist of one production server, one storage unit, one transportation server, and one distribution server. As optimization requirements increase, the essential service system can be adapted to have complex connections between unequal numbers of components. Once construction of an essential service system is completed, it will be registered with the Laws components to begin offering contracts. These contracts are objects that the agents can sense, but have no knowledge of how the contract is filled.

5. Laws

The primary task of Laws is to mediate between agent-agent and agent-object interactions. The main function of the Laws component is to maintain ground truth separate from the agents that are making the decisions of interest to the military decision maker. The only Law for this initial model is the Infrastructure Law.

D. SUMMARY

A DES MAS is able to satisfy the defined requirements. Further, the DES MAS conceptual model provided will supply the required metrics previously discussed for a water essential service simulation. From this conceptual model, a specific software implementation can begin.

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[192] The Sphere Project, p. 65. This extension is directly related to the Sphere Project standards that "assume [a] water point is accessible for approximately eight hours a day only."

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VIII. IMPLEMENTATION OF DES MAS

To conduct my thoughts in such order that, by commencing with objects the simplest and easiest to know, I might ascend by little and little, and, as it were, step by step, to the knowledge of the more complex; assigning in thought a certain order even to those objects which in their own nature do not stand in a relation of antecedence and sequence.

--Rene Descartes[193]

A. INTRODUCTION

Implementation of the conceptual design is the final step in this thesis process. A prototype framework simulation is expressed as event graphs that describe the conceptual model. Extending the event graph foundation, a SimKit software implementation is realized around the Ferber MAS design. Each of the elements in the MAS is precisely defined with loosely coupled event graphs that satisfy the conceptual model. At the completion of the description of the implementation, sample input parameters and computed outputs are provided as a proof of concept.

B. EVENT GRAPHS

The event graph depicts how the design is implemented and translates the component being modeled directly into code. First, an event is defined as a state change that occurs at a specific moment in time. State variables store the data of the simulation in between each event and are initialized by parameters to starting values. During each event's execution, some state variables of the component may change values. At the completion of the logic that changes state variables, other events can be scheduled to occur after a specific amount of time delay. For events that occur immediately, no time delay is shown in the event

[193] Rene Descartes (1960). *Discourse on Method and Meditations*. New York: The Liberal Arts Press.

graph. SimKit's RandomVariates are typically used to generate time intervals and preserve any needed random variable integrity for statistical analysis. These time intervals are represented by T_x_i along scheduling arrows. Output elements passed to other events and conditionals that must be met for the event to be scheduled are represented in Figure 11. For readability of the methods that access state variables, the text under the event graph is shown as direct access code. In addition, a "for each" and a double arrow are depicted, when a similar event is scheduled for all items in a list (see Figure 12). In successive figures in this chapter, events with the same signature imply that both figures are connected and continuous at that event. Lastly, the listener pattern of event graphs allow for one event graph to process state variable changes based on the same event occurring in a previous component (see Figure 13). In order for the second event to execute, both events must have the same signature.[194]

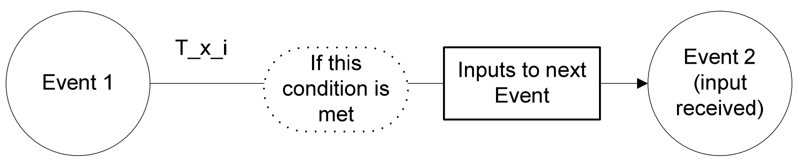


Figure 11. Basic Event Graph Depictions

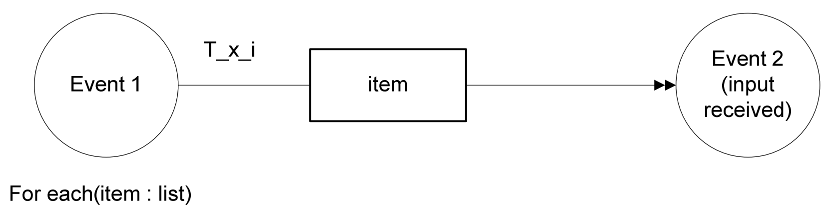


Figure 12. SimKit For Each in a List Extension

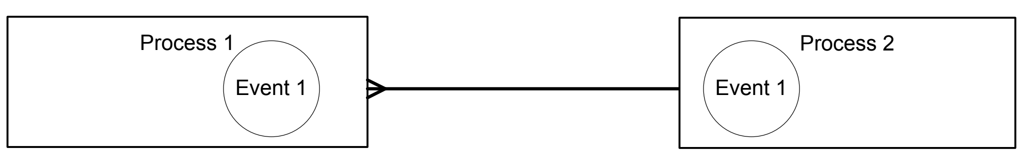


Figure 13. Listener Pattern Event Graph

194 *Component Based Simulation Model with SimKit.* p. 243-247.

C. ENVIRONMENT

The geospatial grid is implemented in a concept form only. Relevant components are assigned a location, but current requirements only relate distance between an agent's home and the distribution source. For proof of concept, a two-dimensional decimal value is used, but can be more complex representations, such as latitude and longitude pairs. If more spatial requirements arise, then a more concrete implementation of the grid may be needed to manage movement and spatial connections.

The social network consisting of the directional ties is also implemented in concept form only. This is accomplished by instilling in the agent a state variable that is a Map of agents and their associated tie.[195] The theory chosen for this proof of concept implementation describes these relationships as a series of three types of ties. First, is the authoritative tie that is generated out of senior/subordinate relationships. Second, the affective tie describes the relationship due to kinship and friendship. Lastly, is the instrumental tie, which is a concept for describing two people with a relationship that is purely business related. Each of these ties has a reference to both agents and a relationship value that scales from -1 to +1.[196] For restoration of essential services, the instrumental tie captures the relevant social model between individuals.

D. AGENTS AND OPERATIONS

During initialization the agent's internal representation of supplies, relationships, and consumption data are all set. Following initialization, the Run event schedules consume events for all positive consumption supplies according to the individual amounts and time intervals (see Figure 14). After every consumption event, an accessible event for either meeting or not meeting the needs provided on the event list (see Figure 15). In addition, the individual

[195] A Map is a software concept that associates a key with a value. In this implementation, an Agent uses HashMaps that uses other Agents as the key that will retrieve the associated tie.

[196] (D. Gibbons, personal communication, 28 Nov 2007).

supply is evaluated against a threshold, in order to determine if the agent needs to acquire more. If the amount on hand is below the threshold, then an agent without an existing contract finds a contract through one of two Operations in the output suite. If an agent has a pre-existing contract, then the agent exercises the second Operation in the output suite by Ordering the supply (see Figure 16).

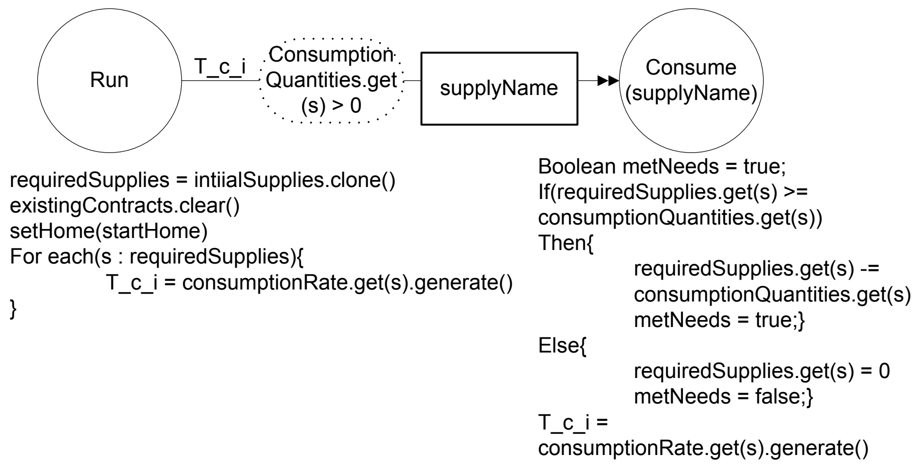


Figure 14. Agent Initialization Event Graph

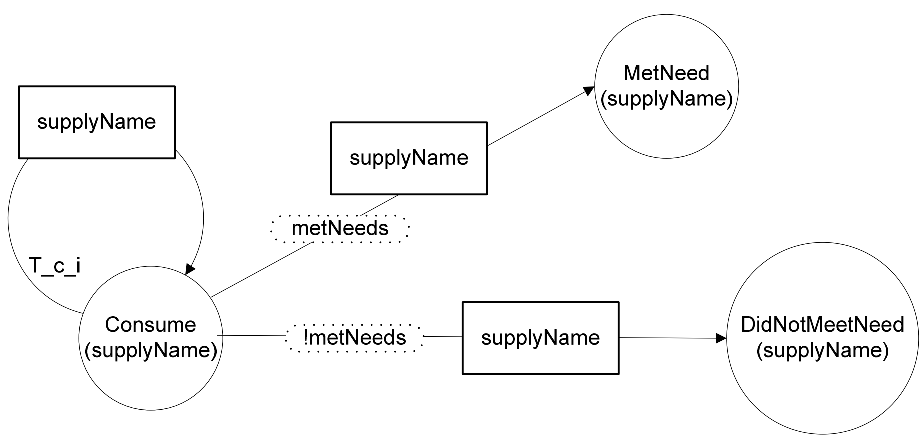


Figure 15. Agent Consumption Event Graph

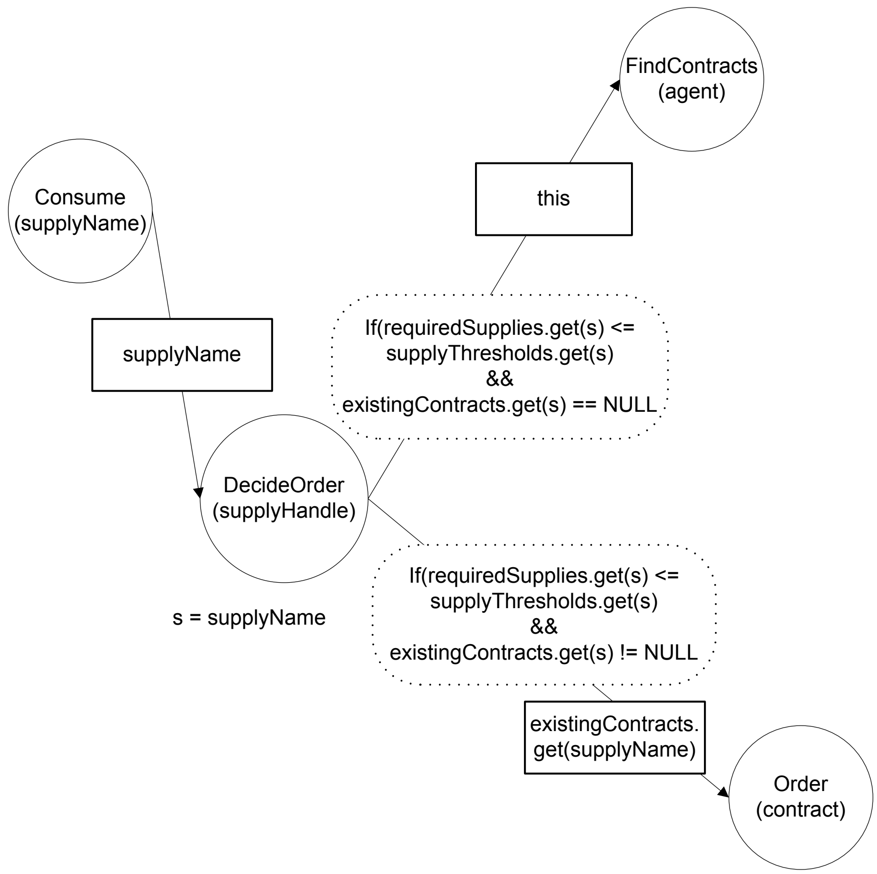
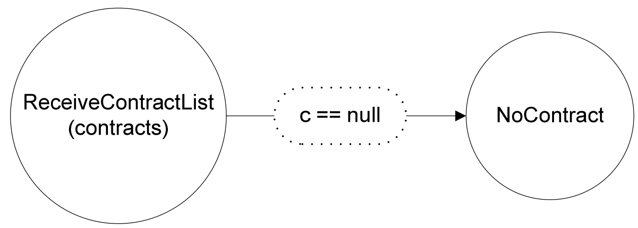


Figure 16. Agent Consumption Results Event Graph

An agent's input suite consists of the events ReceiveEssentialServices (ReceiveES) and ReceiveContracts. Each of these two events begins a decision making process that interacts with the internal representation and results in state variable changes, as well as possible output events. When an agent receives a contract list, it uses an implemented social model to select which contract to use. The output of the contractSelectionMethod is maintained as a state variable, whose primary purpose is to obtain new supplies when needed. If an agent has no contracts that are selected (either due to availability or the implemented social decision making theory), then an accessible event is provided on the event list (see Figure 19). In this thesis, “satisficing” is implemented as a proof of concept contractSelectionMethod.




```
c = contractSelectionMethod.decide(contracts, this.requiredSupplies)
if (c != null)
        existingContracts.put(c.benefit.handle, c.clone())
```

Figure 17. Agent Receive Contract List Event Graph

Satisificing begins with a set of possibilities that undergo a series of culling steps that ends with an arbitration. An agent receives a list of contract possibilities that serve as the input to the contractSelectionMethod. The first culling step removes those contracts that do not provide enough of the resource that meets the agent’s requested amount. In addition, other required minimum standards are culled in order to highlight the agent’s ability to get the resource while maintaining all requirements. Specifically for water, the Sphere Project provides the minimum distance between an agent’s home and the distribution location. (Refer to Figure 9). After this step, the collection of contracts is culled using cost-benefit scaling that is referred to as “praxeic likelihood ratio test.”[197] This test uses a parameter, q, to provide a set of all options that indicate which is more important to the agent, minimizing cost or maximizing benefit.[198] If the result of the second culling is a single contract, then the agent will select the only option available. However, in the case of more than one contract in the

[197] Wynn C. Stirling, (2003), *Satisficing Games and Decision Making With Applications to Engineering and Computer Science,* Cambridge: Cambridge University Press, p. 62-63.

[198] Ibid.

remaining list, an arbitrator is required.[199] The social ties that an agent maintains are used to sort the final list. The agent will then select the highest ranking contract (see Figure 18).

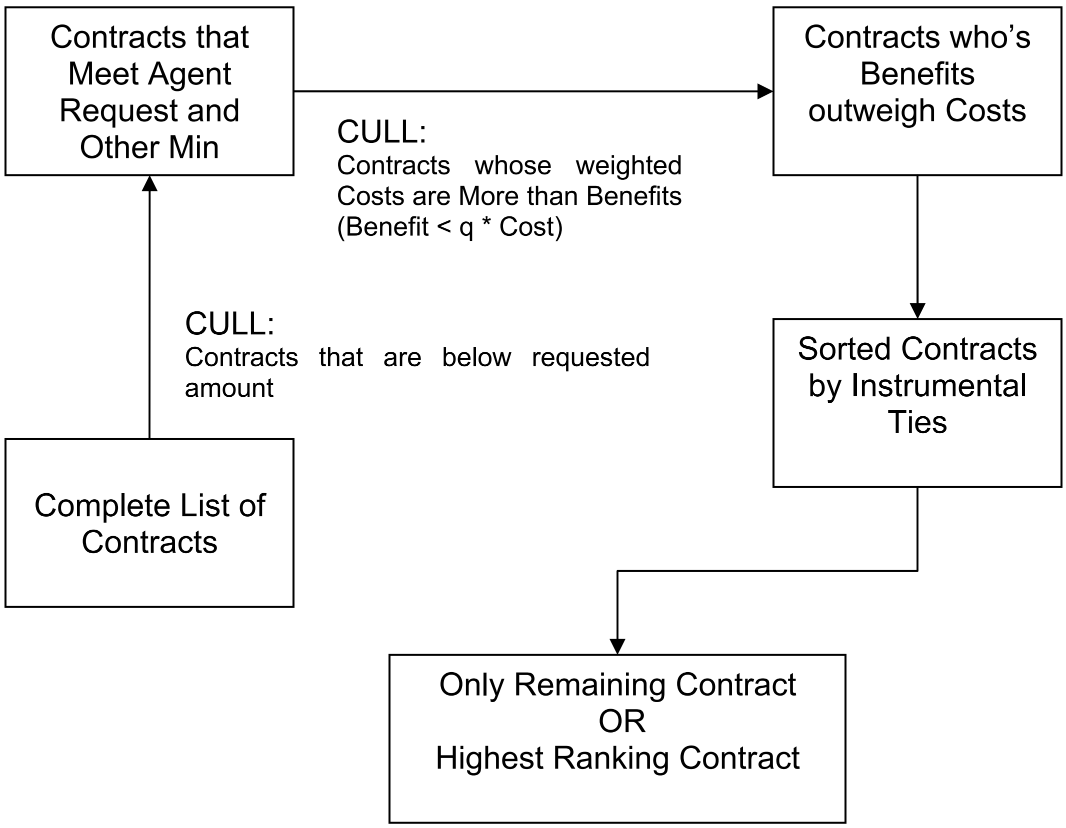
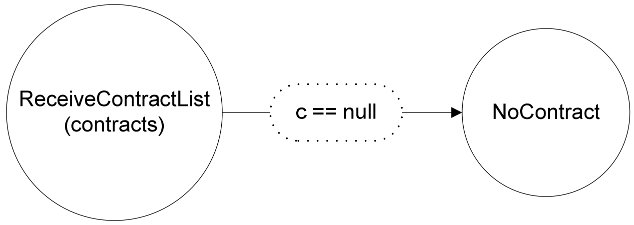


Figure 18. Implemented ContractSelectionMethod: Satisficing

[199] *Satisficing Games and Decision Making With Applications to Engineering and Computer Science*, p. 68-70.




```
c = contractSelectionMethod.decide(contracts, this.requiredSupplies)
if (c != null)
        existingContracts.put(c.benefit.handle, c.clone())
```

Figure 19. Agent Receive Contract List Event Graph

When agents ReceiveES, one of two expected possibilities will be processed. First, if the contract is fulfilled, then the receiver agent receives the contract benefit, spends the contract cost, and evaluates if a new order must be placed immediately. Simultaneously, the supplier agent receives the cost of the contract.[200] However, the agent may receive a contract that could not be fulfilled, due to service problems, lack of adequate quantities, etc. This rejected contract is also provided as an accessible event for possible inputs to social model add-ons (see Figure 20).

[200] In the this simulation, the cost that is being implemented is "Money." Money is just a placeholder that can be used as a method of counting or other analysis. Any level of complexity regarding cost and benefits of exchanging resources can be implemented.

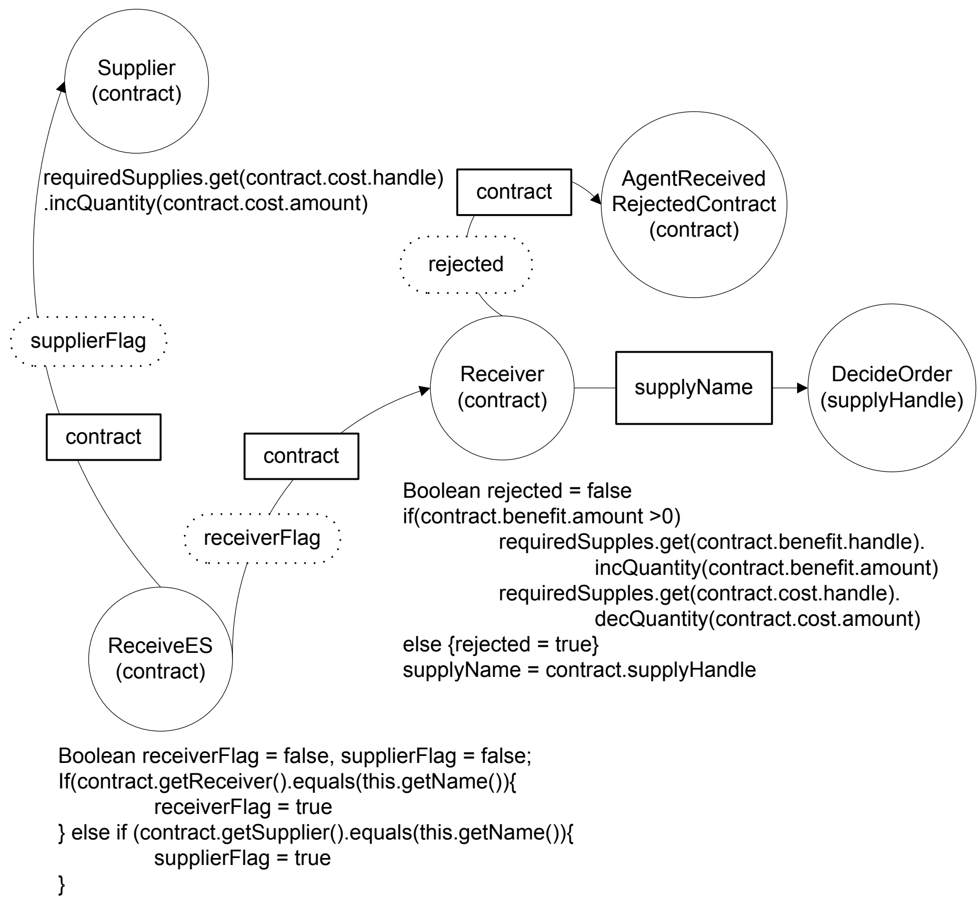


Figure 20. Agent Receives Essential Service Event Graph

E. OBJECTS

Basic elements of contractual exchanges and an adapted simple server component represent objects in the simulation. The relevant concepts in a contractual exchange to an essential service simulation are the receiver, the supplier, the distribution location, the cost, and the benefit. Components of the simulation will accept and pass on contracts in order to track the essential service along the needed resource life cycle. With this basic building block, complex contractual agreements can be implemented as required.

For the server components, an arrival event evaluates the arriving contract for relevant queue joining rules and either rejects the contract or adds it to the queue (see Figure 21). The start service event is scheduled if an available server can begin the prescribed process. Each server uses Random Variates that are provided by the designer to stochastically model the service time. At the end of the service time, an end of service event communicates that the contract has completed the process, specifically either production, transportation, or distribution. The last step in the end of service event is to begin another start service if the queue has an awaiting contract (see Figure 22).

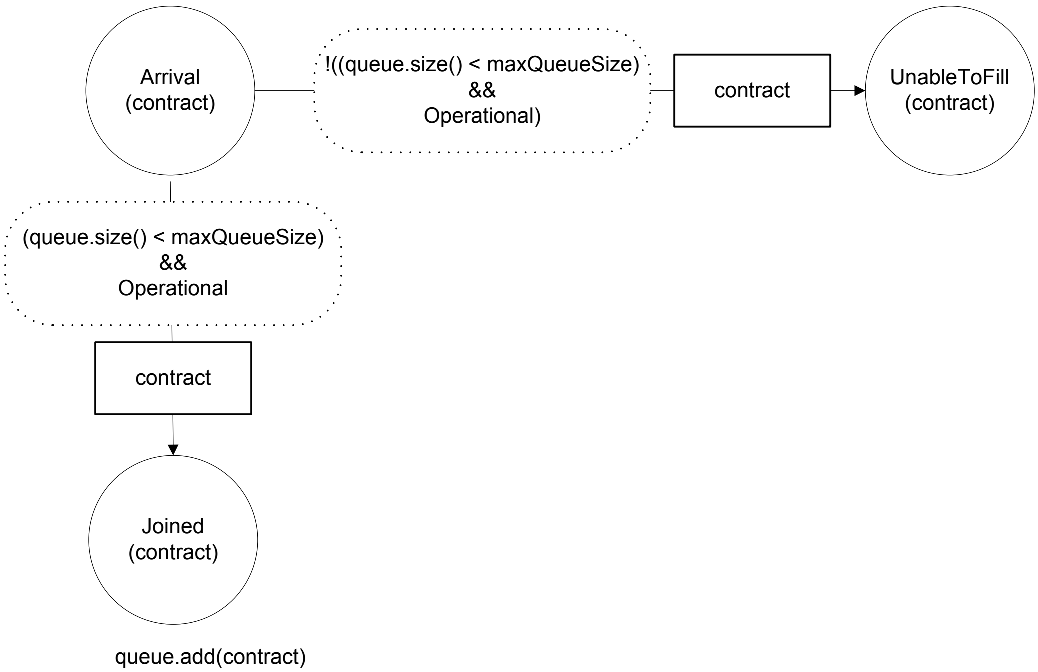


Figure 21. Essential Service Server Arrival Event Graph

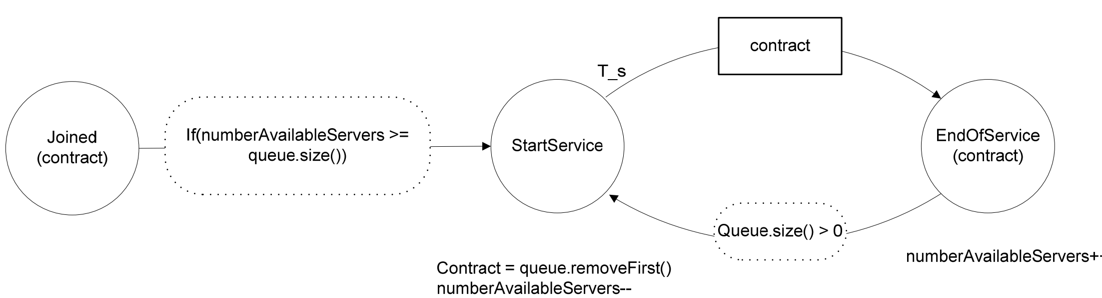


Figure 22. Essential Service Server Component Event Graph

In order to integrate a generic arrival component (see Figure 23), a single arrival extension is required. The arrival extension translates a self-scheduling arrival event into a contract object that represents the production of a resource. This extension seamlessly attaches to the existing server component as described above (see Figure 24).

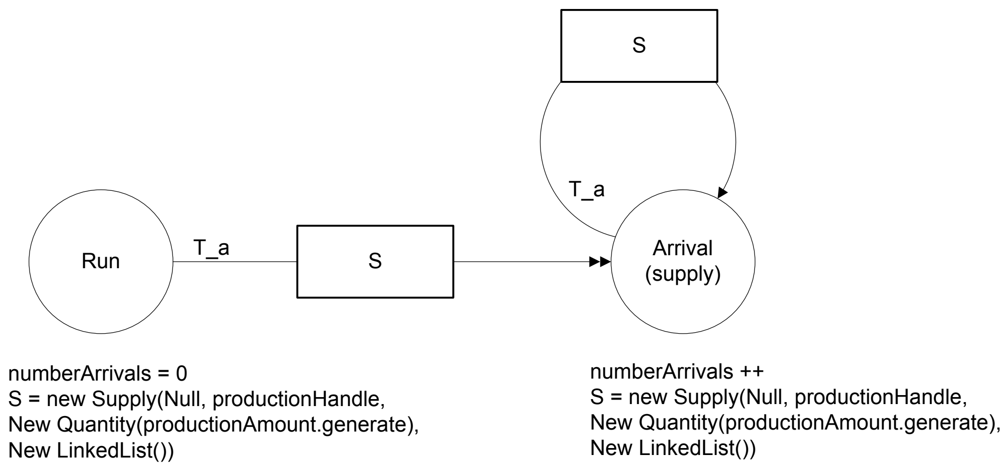


Figure 23. Generic Arrival Component Adapted to Generate Supply Production

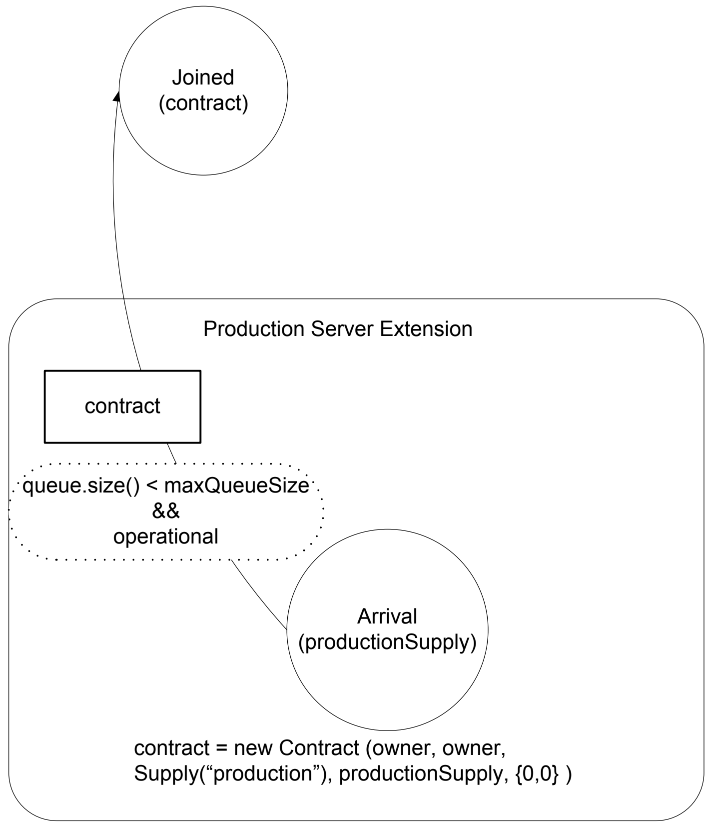


Figure 24. Essential Service Production Server Extension

Another modification to the server component is needed in order to evaluate some of the requirements from distributing essential services. The concept of "hours of operation" is implemented through two parameters. Both parameters are relevant to the time scale being modeled, and are stored as a "start time" and "stop time" for each server (see Figure 25). The functionality of these parameters is to reject incoming contracts when a server is not between the start and stop times (see Figure 21 and Figure 24). If more complex time management of existing essential service servers is required, then the simple server described can be modified to explore that problem space.

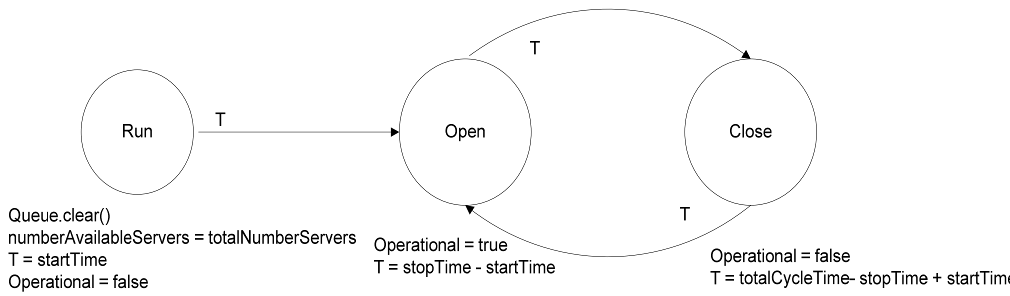


Figure 25. Essential Service Server Hours of Operation Event Graph

In between the production and the transportation components, a storage object components requests for contracts and determines contract supportability (see Figure 26). A single storage object for each production component allows different capacity levels to be evaluated and provides a reservoir of supply during surge demands on the distribution system. In addition, a store event that tracks quantities available for distribution is connected to the production server's output (see Figure 27).

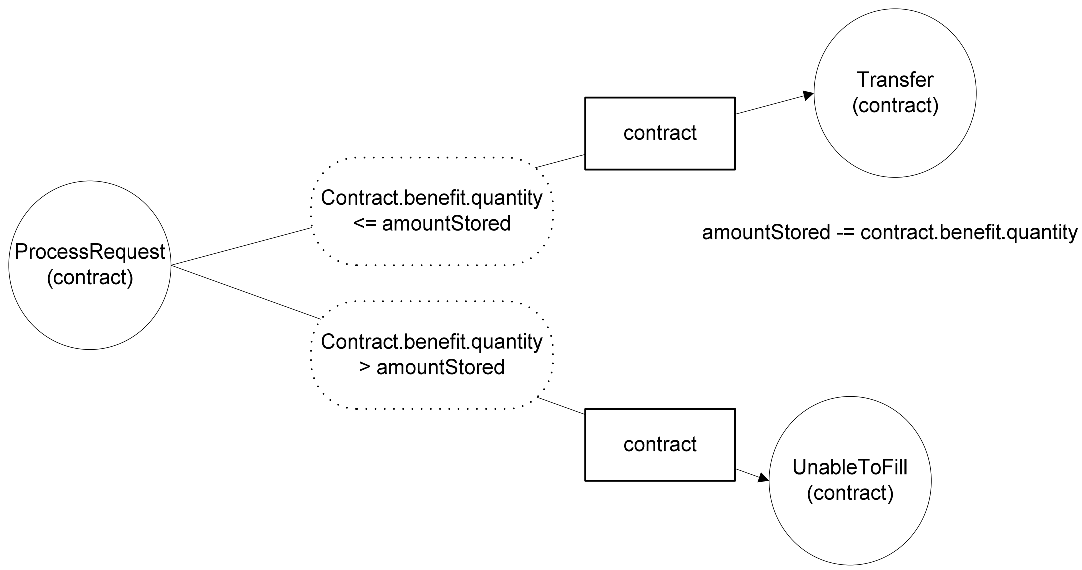


Figure 26. Essential Service Storage Object Component Request Event Graph

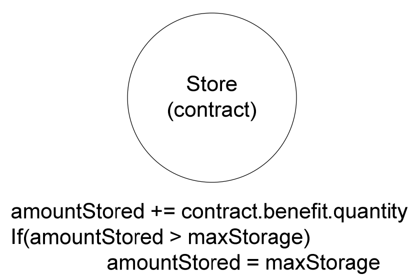


Figure 27. Essential Service Storage Object Accumulation Event Graph

All of these objects are wrapped in a single Essential Service System object that coordinates communication between events internal to the Essential Service System and components external to the Essential Service System (ESS) (pictorially, THIS represents the wrapper object in Figure 28). Furthermore, since a key capability of the DoN is to rebuild essential service systems, systems that are under construction require a functional time that indicates the system is ready to provide services (see Figure 29).

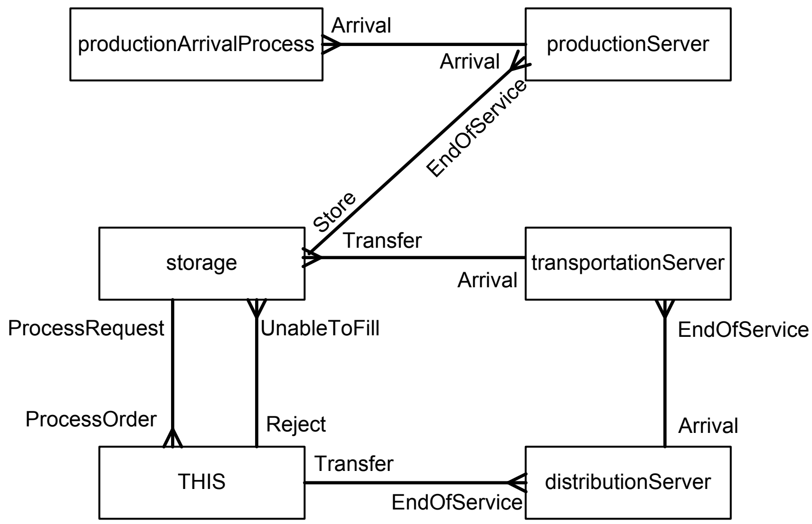


Figure 28. Essential Service System Connection Graph

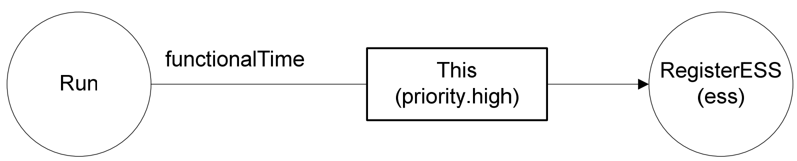


Figure 29. Essential Service System Functional Time Event Graph

F. INFRASTRUCTURE LAW

In the implementation of this concept, SimKit DES methodology had to be extended in order to preserve the loosely coupled design. The Law component must notify only relevant agents or ESS and insulate these communications from components that are not involved. By using standard listener paradigms, every agent “hears” every message broadcast from the Law component. Likewise, every ESS will attempt to handle every contract that is passed by the Law component. This challenge was overcome by extending SimKit and capitalizing on a SimKit entity’s ability to schedule events directly. In essence, since the entire agent event graph is contained in the contract object, the Law event graph gains access to the agent’s event graph (see Figure 30). The only requirement on the framework is that the agent and object components are extensions of SimkitEntityBase. By adding this design capability, multiple SimKit event graph components can be aggregated and be passed as inputs, while preserving a well-defined and loosely coupled methodology.

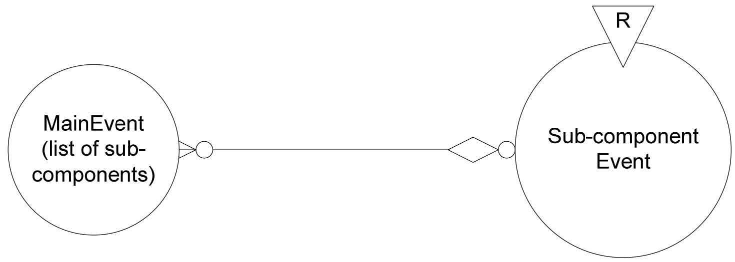


Figure 30. Extension to SimKit's Ability to Schedule Sub-Component Events[201]

Using this new capability, the Laws begin by registering agents and functional ESS. As new ESS are constructed, all registered agents are sent an updated list of functional systems that will allow the agent to reconsider contract selection (see Figure 31). Then the law will monitor the simulation for incoming messages to process. Law events are processed to impose communication restrictions and to maintain a separate ground truth mediator. In this implementation, no communications restrictions are emplaced. For relevant Agent-Agent communications, the agent receives knowledge of all existing contracts. Agent-ESS communications are represented as a pass through bridge (see Figure 32). If a contract is rejected from the essential service system, all quantities of the contract are set to 0, and the receiver is notified that it has been rejected (see Figure 33). Fulfilled contracts are communicated to both the receiver agent and the supplier agent (see Figure 34).

[201] A new format of scheduling arrow is shown in Figure 30 depicting scheduling a sub-component event indicated by the ID tag.

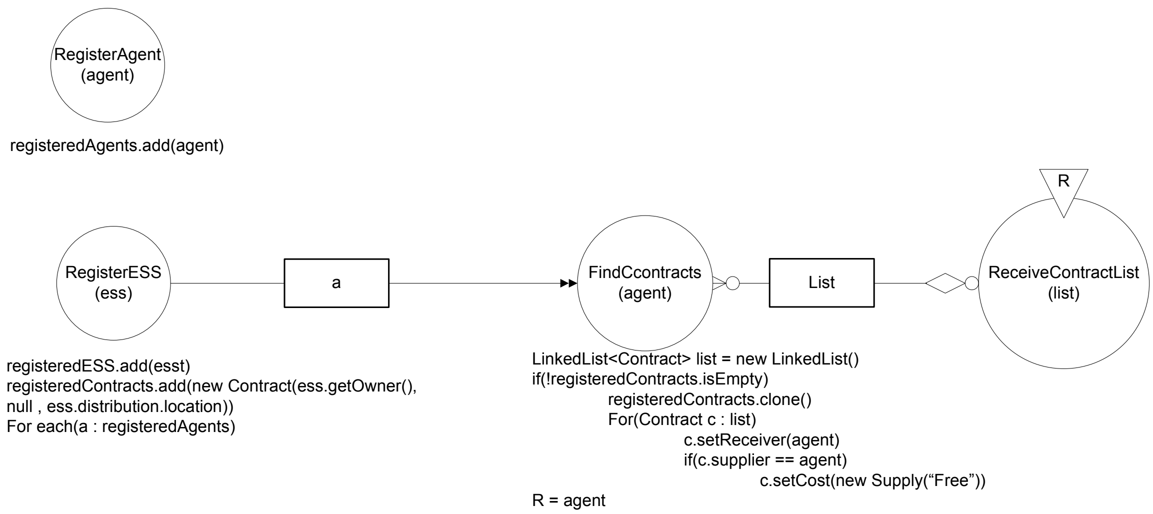


Figure 31. Infrastructure Law Registration Event Graphs

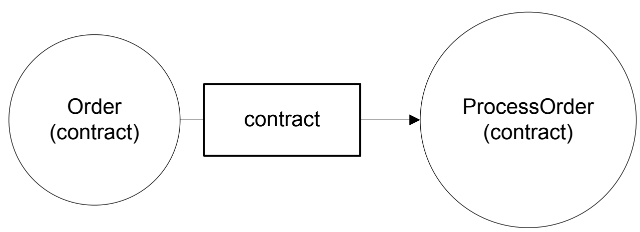


Figure 32. Infrastructure Law Pass Through Processing Agent-ESS Communication

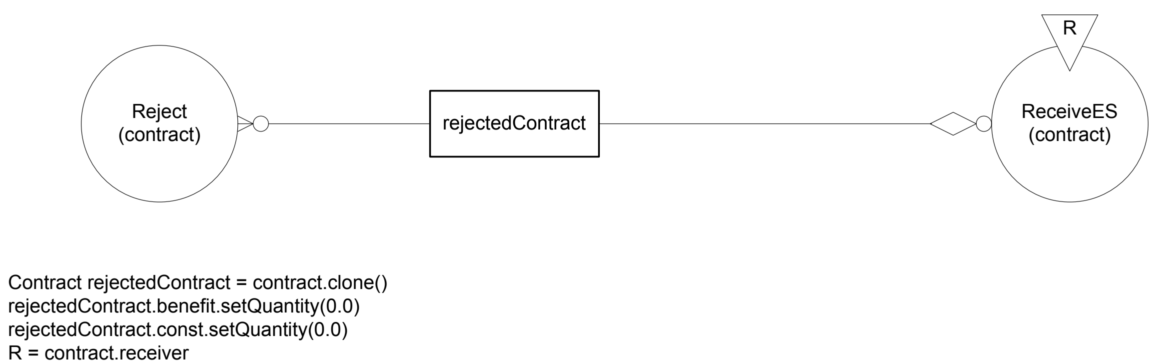


Figure 33. Infrastructure Law Processing Rejected Contracts to the Receiver Agent

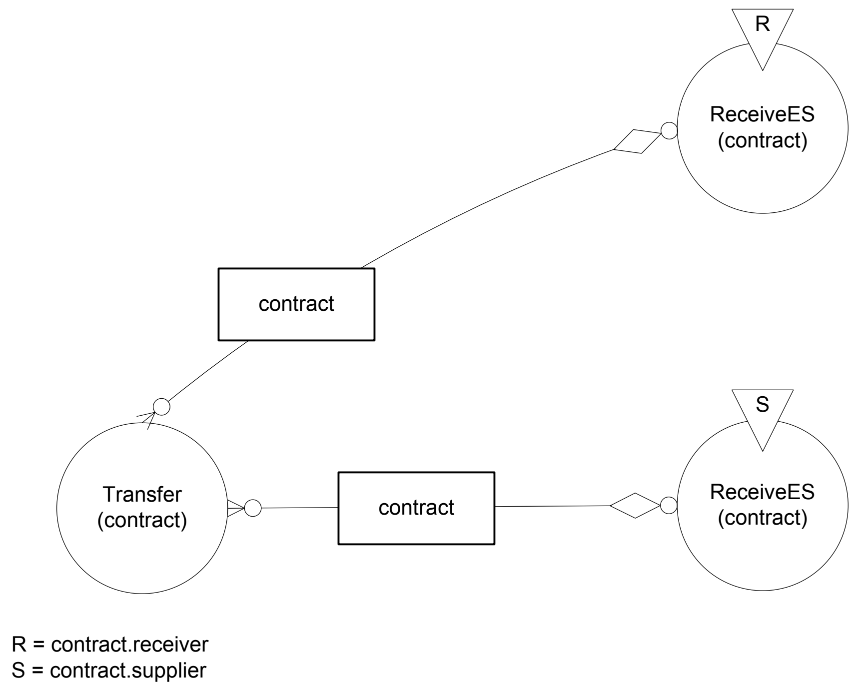


Figure 34. Infrastructure Law Processing Fulfilled Contracts to the Receiver Agent and Supplier Agent

G. SAMPLE RUN

1. Water Input Parameters (All Values are in Litres)

DAILY_WATER_CONSUMPTION_AMOUNT = 15.0; //Sphere project recommends 15 litres of water for all uses per day

STARTING_WATER_AMOUNT = 0.0; //Disaster scenario means everyone has 0 water

THRESHOLD_WATER_AMOUNT = 15.0; //One day's worth of water

DEFAULT_WATER_CONTRACT_AMOUNT = 10; //Sphere project recommends that the queuing time metric is based on ability to fill a 10 litre container.

2. Other Requirement Input Parameters

MAX_DIST = 500.0; //maximum distance from water distribution source to an agent's home measured in meters

STARTING_MONEY_AMOUNT = 10.0; //money only used to count transactions. Every transactions "costs" 1 unit of money.

3. Time Input Parameters

dailyRate = 24; //every consume event is based on 24 hour consumption at a "constant" rate

numberOfSimDays = 5; //number of cycle periods that are run for the simulation

Schedule.stopAtTime(dailyRate * numberOfSimDays); //stops the simulation after the relevant number of cycles

4. Agent Input Parameters

q1 = .5; //agent 1 cost weighted parameter. Zero can mean that the agent is willing to accept any cost.

q2 = .8; //agent 2 cost weighted parameter. Zero can mean that the agent is willing to accept any cost.

{0.0 , 0.0} //agent 1 start location

{0.0 , 0.0} //agent 2 start location

agent1FeelsAboutAgent2 = 0.8; //agent 1 instrumental tie to agent 2

agent2FeelsAboutAgent1 = 0.5; //agent 2 instrumental tie to agent 1

5. Essential Service System Input Parameters

productionArrivalMean = 1.0; //mean time interval for production arrival events productionRateMean = 4.0; //mean time for production end of service events

productionAmountMean = 35.0; //mean quantity of produce water

productionMaxQueueSize = 1; //maximum number of supply elements awaiting production start service. One is sufficient to always have the production server “primed” to constantly produce water.

maxProductionAvailServers = 1; //maximum number of supply elements that can be handled at once. Can translate to number of naval ships producing water

productionStartTime = 0; //hour that operation begins on a 24 hour clock cycle

productionStopTime = 24; //hour that the operation terminates on a 24 hour clock cycle

productionLocation = {300.0 , 400.0}; //Conceptual grid location of the production site

maxStorageCapacity = 50.0; //maximum number of litres that are stored before transportation

transportationRateMean = 0.0; //mean time for transportation end of service events

transportationMaxQueueSize = 1; //maximum number of contract elements awaiting transportation.

transportationMaxAvailServers = 1; //maximum number of servers that can handle one contract each

transportationStartTime = 0; //hour that operation begins on a 24 hour clock cycle

transportationStopTime = 24; //hour that the operation terminates on a 24 hour clock cycle distributionRateMean = .5; //mean time for distribution end of service events

distributionMaxQueueSize = 2; //maximum number of contract elements awaiting distribution

distributionMaxAvailServers = 1; //maximum number of servers that can handle one contract each

distributionStartTime = 0; //hour that operation begins on a 24 hour clock cycle

distributionStopTime = 24; //hour that the operation terminates on a 24 hour clock cycle

distributionLocation = {300.0 , 400.0};//Conceptual grid location of the distribution site

functionalTime1 = 0.0; //time delay before the essential service system will be available for contracts.

totalCycleTime = 24; //total time per cycle of operation. startTime and stopTime are less than this value and are in reference to it.

6. Output

first guy has water: 10.0

first guy has money: 3.0

First guy went thirsty: 1 times

second guy has water: 20.0

second guy has money: 17.0

Second guy went thirsty: 1 times

Average queue time: 0.12

Average service time: 0.4

H. SUMMARY

This implementation serves as a proof of concept implementation of the conceptual model and demonstrates key concepts of DES MAS design. By maintaining the loosely coupled philosophy throughout the design and implementation procedures, each component can be exchanged for another representation of the component process. Furthermore, these extensions to standard event graph design allow simulation designers to consider many different levels of aggregation while maintaining loose coupling. From this simulation implementation, many areas for future work are revealed and several conclusions can be drawn, which are discussed in the final chapter.

IX. CONCLUSIONS, RECOMMENDATION, & FUTURE WORK

> *The scarcity of fresh water and food could be an even greater concern. Today, more than a billion people are without access to an improved water supply...By 2025, more than half the global population will live under water stressed or water scarce conditions.*
>
> James T. Conway
> Commandant of the Marine Corps
> Marine Corps Vision and Strategy 2025

A. CONCLUSIONS

With the right procedures and practices, simulations are a force multiplier that help DoN prepare for new missions. Overall, this thesis adds to the M&S of military support to SSTR Operations body of knowledge. First, a process was followed that allowed initial requirements and concepts to grow into a proof of principle simulation. Second, during the research effort, references and documents describing the SSTR problem were assembled. Third, in the absence of DoN requirements, several requirements were presented as a starting point. Lastly, based on the above requirements, a loosely coupled DES MAS conceptual model was designed and implemented.

1. Process

Since modeling all aspects of SSTR is currently unobtainable, this thesis presented a process to promote a solution. SSTR as a whole is a wicked problem that needed to be broken down into small addressable pieces. How that was accomplished was by first understanding the problem and scoping it into a manageable question. Once the question was clear, then the requirements were defined to answer that question. This thesis was able to do this by scaling the SSTR problem domain to restoration of essential services for water. From these requirements, metrics that gauge civilian population's essential needs were produced and integrated with social theories. Those same metrics can be used to evaluate how DoN meets those needs during military support to SSTR operations. Furthermore, a conceptual model was designed to satisfy the requirements. After the completion of the conceptual model design, the implementation was created to show a proof of principle.

2. Repository

Several agencies are attacking the problem of SSTR from their respective perspectives. Unfortunately, what is lacking is the unity of effort. This thesis crossed agency boundaries and collected relevant documents from each of the major actors in solving this problem. While providing history and background, this thesis establishes a foundation in which any organization can use as a starting point. The documents used as reference are critical foundational factors that need to be kept current and relevant. The MOVES Institute currently serves as the storehouse for the documents collected and maintains the "cutting edge" on M&S requirements for military support to SSTR Operations.

3. Requirements

The hardest task for a user of a model is to identify requirements and for a designer to capture those requirements. Sometimes a simulation is identified as an answer before the questions are even asked. Once the definite problem statement is established, then a list of requirements can be generated. The requirements must not be tied to a specific implementation paradigm. This thesis presented modeling and architecture requirements. Although these requirements are not sufficient, they are necessary and serve as an example to begin solving this problem domain.

4. Conceptual Model / Implementation

A well-defined conceptual model is only possible if good requirements are provided. Once a conceptual model is designed, the implementation choices must be constantly evaluated against this design. Further, if the conceptual model requires extensions or additions to existing capabilities, the model designer should provide recommended capabilities. This thesis' conceptual model maintains the loosely coupled nature that provides the capability to exchange components as theories evolve. Moreover, it satisfies all established requirements from Chapter III and serves as a prototype framework that can be expanded. Ultimately, it is not THE solution but is a step in the right direction towards a solution.

B. RECOMMENDATIONS

A new problem set that expands across a myriad of disciplines causes friction and confusion that prevents collaboration, progression, and communication between the different groups. This thesis acts as evidence showing how partial progress can be made with modeling and simulation of solutions for wicked problems. The following recommendations can further overcome the areas of friction and confusion that prevent M&S professionals from meeting the needs of the user, helping all parties communicate, and building an environment of cooperation.

1. Use the Process

Answers never arrive before the question. As obvious as this statement is, software designers continue to provide simulations that do not answer the users' requirements. The designers continue to hold on to the notion that the users are unable to comprehend and communicate what they want. It leaves the users frustrated and not using the end-product. This is true for simulations. In order to have a viable and useful tool, the users, SMEs (both 'soft' and 'hard' sciences), and M&S experts have to understand the problem domain enough to define specific modeling requirements. M&S experts should resist the urge to generate a conceptual model in a complex problem domain without these requirements. By using a process, such as the one followed in this thesis, the end-result will have more utility to users than a great tool that was built while still looking for a requirement to fill.

2. Translation

Since SSTR Operations involve several different agencies that have their own unique terminology, there is a need to bridge the communication gap. The suggestion is not to make one standard terminology, but merely to define an agreed upon “translation dictionary.” Moreover, if concepts in one domain do not exist in another, then these concepts should be explained and documented. Many times different domain SMEs would have different understanding of words as foundational as “random.” To one social SME, “random” means chaotic and without predictability. But to an OR SME, “random” can mean a well understood and statistically valid random variable. This “translation dictionary” is vital to facilitating the cooperation and understand that this problem domain demands.

3. Cooperation

No one domain is going to solve the SSTR problem. Not only does policy dictate that all domains shall work together, but the foundational definition of today’s Operational Environment explicitly states different domains are interconnected. Each domain has SMEs that can provide insight on the road to the final solution. With the aid of a “translation dictionary” described above, qualitative science professionals can understand the quantitative science professionals and vice versa. Furthermore, since the social domain is crucial to solving the human aspects of the Operational Environment, it is imperative that their expertise is integrated into all aspects of military training and planning. Without them, the military support to SSTR will not succeed.

C. FUTURE WORK

During this research, several areas presented themselves as needing further exploration. The conceptual model and implementation must begin the Verification, Validation, and Accreditation process. Further, the conceptual model can be extended beyond water quantity. Also, interoperability needs to be investigated. Scenario definition files would assist integration with existing kinetic simulations that are adopting standards in this area. In addition, more work is needed regarding integrating different social models. Lastly, to capture a complete picture, analysts can expand collection of metrics to a more comprehensible list.

1. Verification and Validation

The next step after model implementation is to verify that the software implementation meets the specifications in the conceptual model. After verification is satisfactorily completed, the model should undergo validation. Several techniques include sensitivity analysis, boundary analysis, and initial conditions analysis. In addition, the social models chosen for proof of concept implementation should be verified with SMEs in order to gain confidence that the model is based on relevant social theory and to find suitable parameter values for humanitarian assistance situations.

2. Conceptual Model Extensions

As stated in Chapter IV, water has other standards beyond quantity. A logical next step is to extend the conceptual model to account for “quality” and “use” standards. In addition, the conceptual model was intentionally designed as easily adaptable to other essential services. This adaptability can be explored to model other aspects of restoration of essential service spelled out in FM 3-0, such as food, basic sanitation, shelter, medical care, and prevention of epidemic disease.

3. Military Scenario Definition Language (MSDL)

To date, no one scenario file format has been accepted across the services. However, the Simulation Interoperability Standards Organization (SISO) is attempting to bridge this gap with a proposed standard for the Military Scenario Definition Language (MSDL). The current version of MSDL does not include any structure that considers non-kinetic effects such as supplies, resources, and humanitarian assistance. MSDL is the emergent standard. Structures described in this thesis may benefit the broad M&S community as future extensions to the MSDL standard. The approach will be briefed to the SISO MSDL Product Development Group at the 2009 Spring Simulation Interoperability Workshop. If other structures are adopted to store scenario information, then this simulation model will need to be adapted in order to take advantage of emerging standards.

4. Integrate Social Model Add-ons

TRAC-Monterey is conducting research for Representing Urban Cultural Geography (RUCG). This research is evaluating a civilian population's changing positions on issues that are belief-based. The research uses the same MAS design from the conceptual model, and integration between the two simulations would be straightforward. By combining the two simulations, analysts and instructors would have a tool that simulates changing positions on issues due to restoring and providing water to the population.

Other social theories represent relationship as dynamic social models with affinities that change over time. These models anticipate an input event that simulates an interaction between two or more agents that will propagate through the connected individuals.[202] As discussed with SimKit wrapping techniques, this simulation can provide MetNeeds, DidNotMeetNeeds, ReceiveES, and other events that are translatable into inputs for the dynamic social model.

Furthermore, changes to the social model could influence the social ties in this simulation, causing possible renegotiations of contracts. By adding social theories to the essential service simulation, the military decision maker can explore restoration of essential service actions and effects on the populace.

5. Additional Metrics

During the development of metrics for the simulation, this thesis focused on defining the core requirements that would provide some insight into the problem domain. Additional work is needed to fully develop the complete scope of metrics that can assist more fully in answering questions outside of the core requirements. As an example, metrics that evaluate the degree of failure to meet "hard line" quantities can be calculated from data that is already present in the conceptual model. Metrics such as these can provide "first-pass" insights that assist the analyst or instructor in measuring failures in terms of: "how close to success is the failure."

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[202] Christian J. Darken and John D. Kelly (2008), "Individualized NPC Attitudes with Social Networks," *Game AI Programming Wisdom 4*, Charles River, S. Rabin editor.

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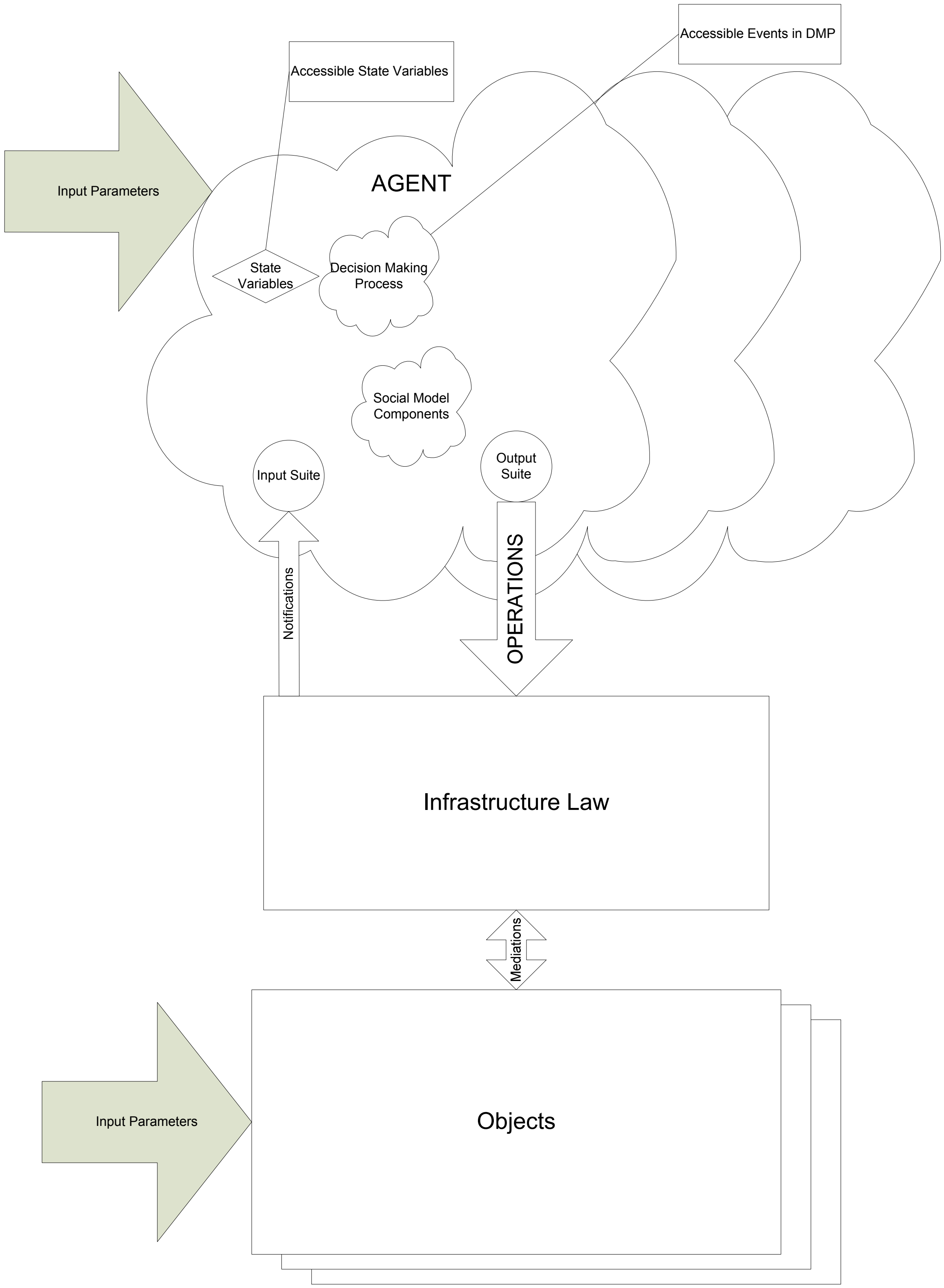
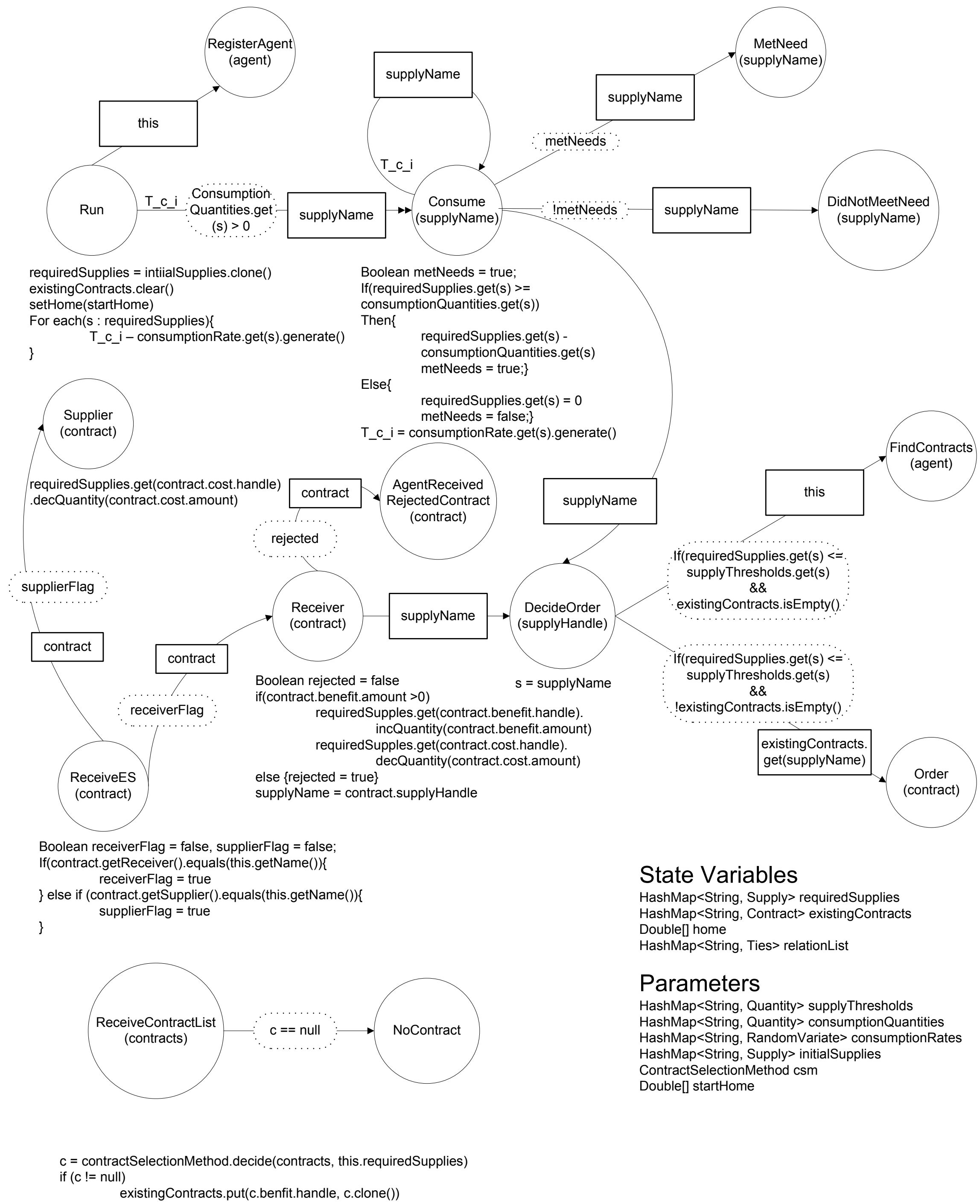
APPENDIX

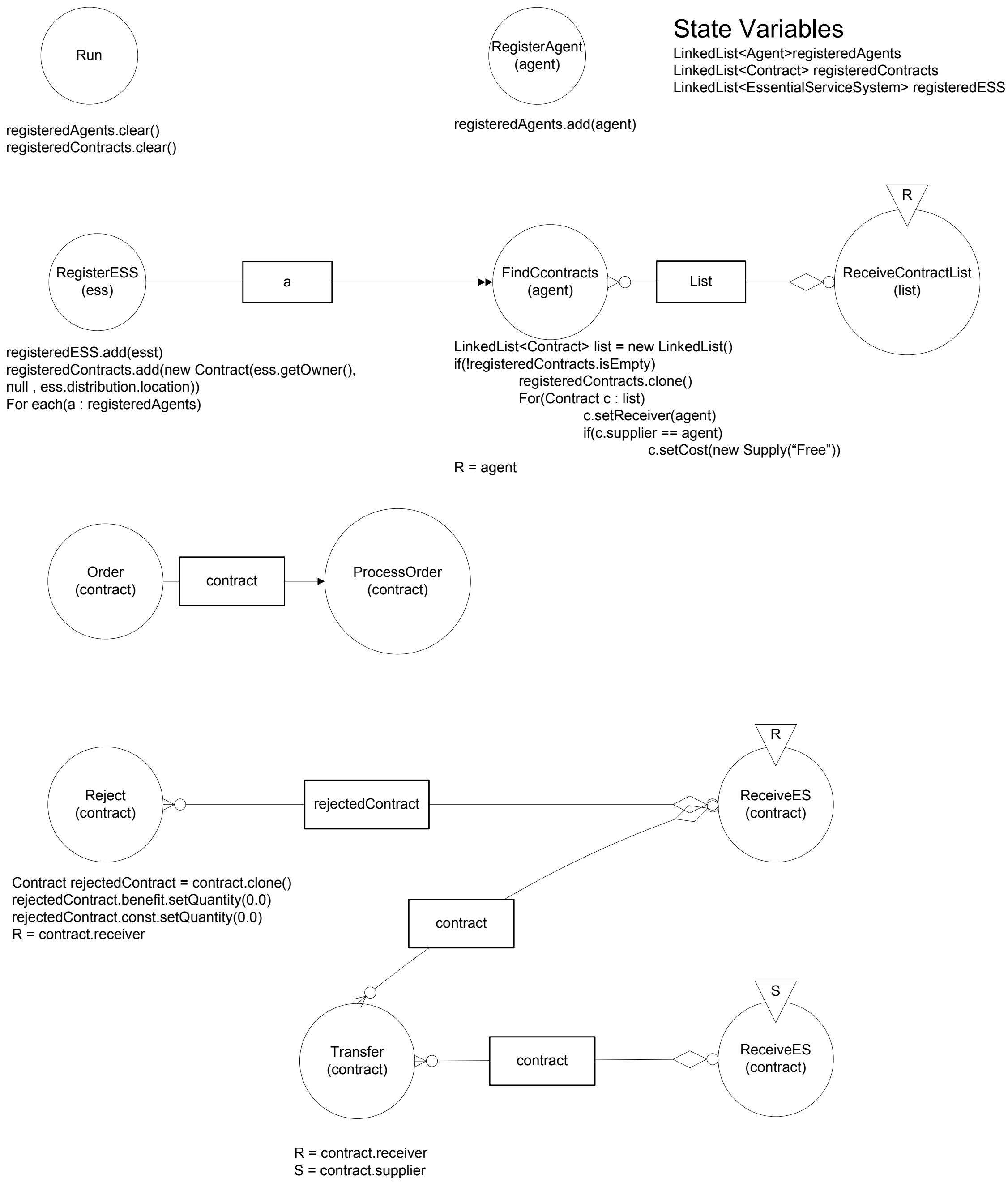
The follow page is the complete graphic representation of the conceptual model provided to show how the different components relate to each other. The follow-on pages are the complete event graph depictions of the implementation explained in Chapter VIII.



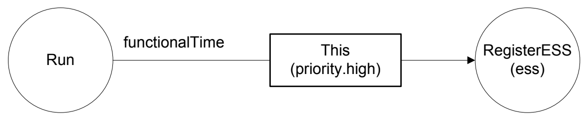
CONCEPTUAL MODEL



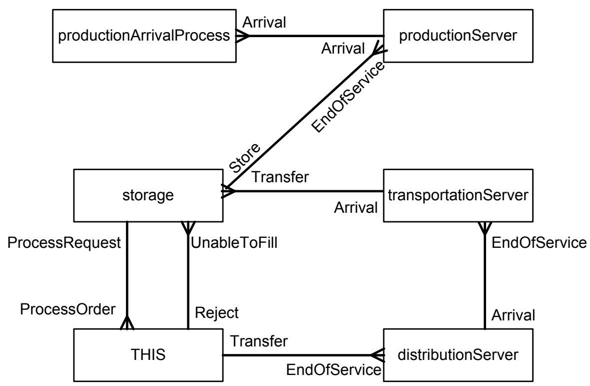
AGENT EVENT GRAPH



INFRASTRUCTURE LAW EVENT GRAPH



setOwner(intialOwner)
setProductionArrivalProcess(new ArrivalProcess(producctionRate))
setProductionServer(new Production_ESS_Server(productionMaxAvailServers,
productionMaxQueueSize, productionRate, owner, productionLocation,
productionStartTime, productionStopTime, totalCycleTime))
setStorage(new StorageObject(maxStorageCapacity))
setTransportationServer(new ESS_Server(transportationMaxAvailServers,
transportationMaxQueueSize, transportationRate, owner, transportationLocation,
transportationStartTime, transportationStopTime, totalCycleTime)))
setDistributionServer(new ESS_Server(distributionMaxAvailServers,
distributionMaxQueueSize, distributionRate, owner, distributionLocation,
distributionStartTime, distributionStopTime, totalCycleTime)))



Component Processes

ArrivalProcess productionArrivalProcess
Prodcution_ESS_Server productionServer
StorageObject storage
ESS_Server transportationServer
ESS_Server distributionServer

State Variables

Agent owner

Parameters

(Main process)
Agent intialAgent
double functionalTime

(Component Processes—production, transportation, distribution)
RandomVariate processRate
int processMaxQueueSize
int processMaxAvailServers
double[] processLocation
double startTime
double stopTime
double totalCycleTime

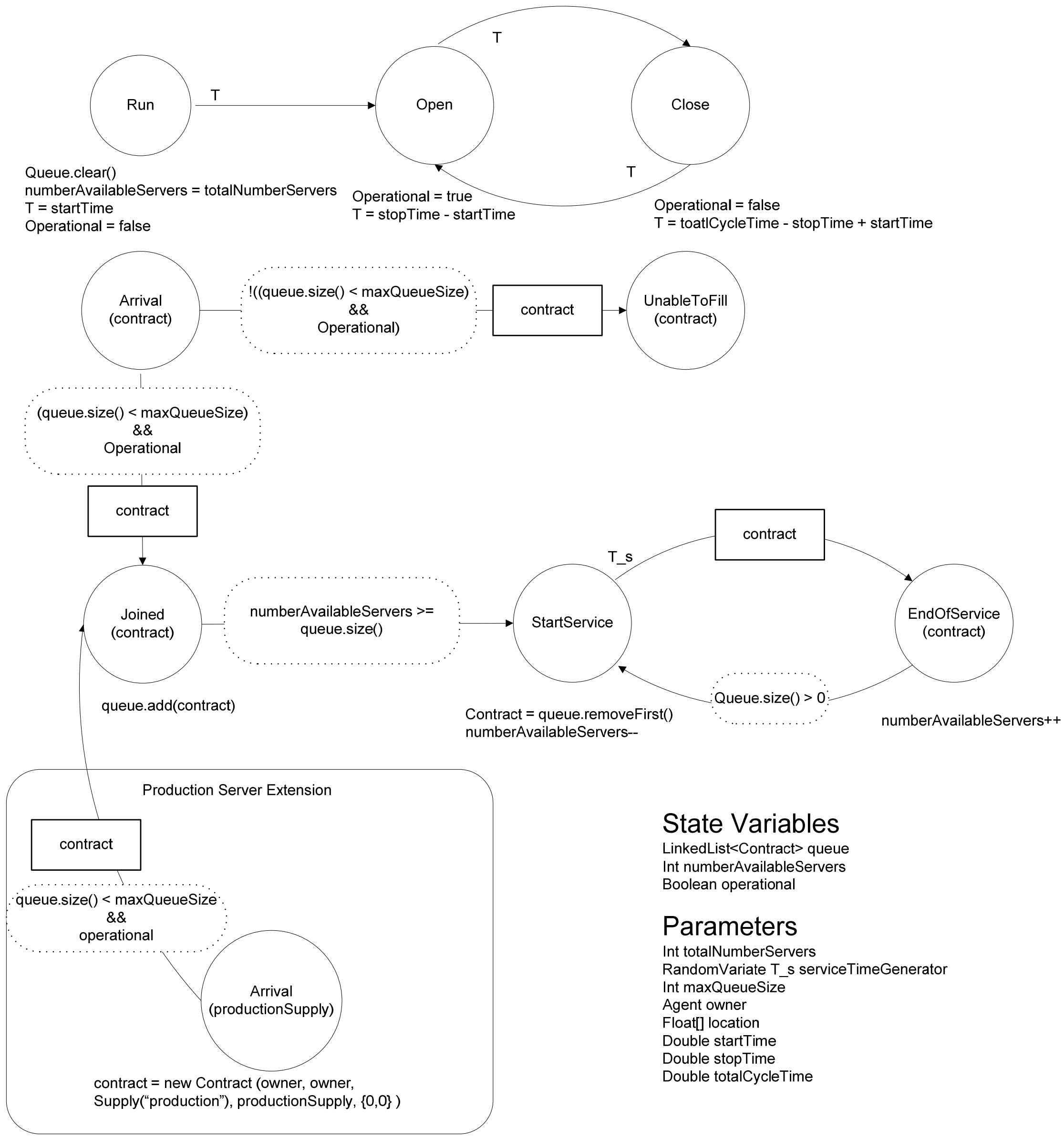
(production arrival extension parameters)
String essHandle
RandomVariate productionArrivalRate
RandomVariate productionAmount

(storage object)
double maxStorageCapacity

Statistics

SimpleStatsTimeVarying distributionQueueTime
SimpleStatsTimeVarying distributionServiceTime

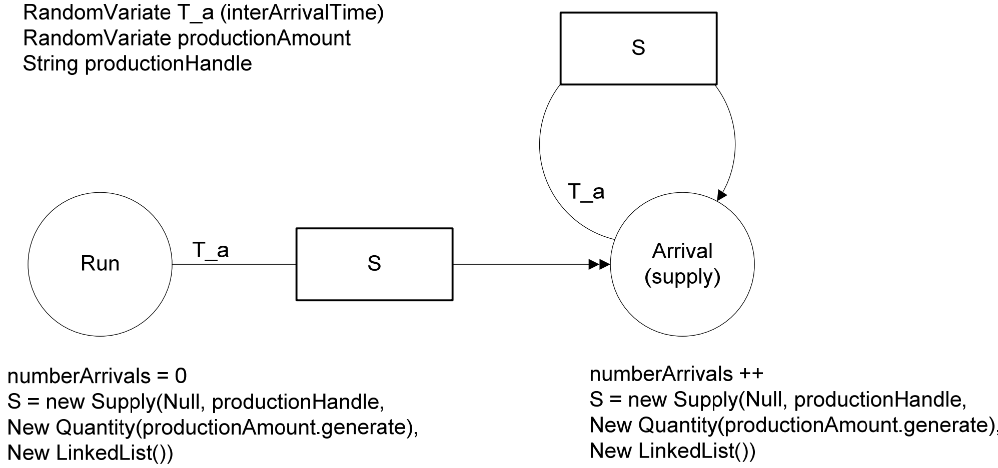
ESSENTIAL SERVICE SYSTEM EVENT GRAPH



ESSENTIAL SERVICE ADAPTED SERVER EVENT GRAPH

State Variables
Int numberArrivals

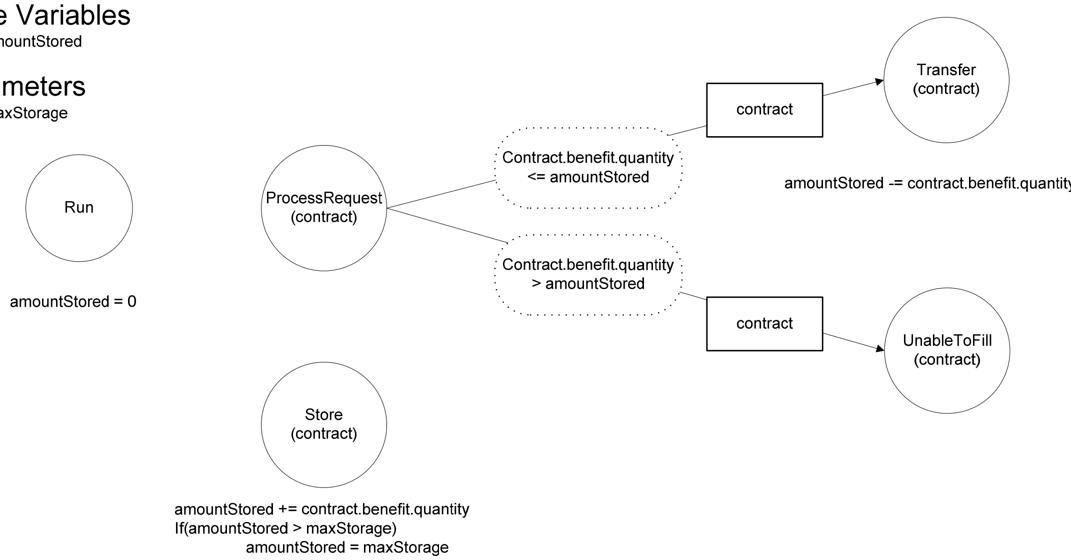
Parameters
RandomVariate T_a (interArrivalTime)
RandomVariate productionAmount
String productionHandle



ADAPTED ARRIVAL PROCESS EVENT GRAPH

State Variables
Float amountStored

Parameters
Float maxStorage



ESSENTIAL SERVICE STORAGE OBJECT EVENT GRAPH

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    Irregular Warfare Analyst
    J-8 Warfighting Analysis Division

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    Program Analysis and Evaluation (PA&E)
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